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HANDHELD CONCEALED WEAPONS DETECTOR DEVELOPMENT

Jaycor, Incorporated

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13. ABSTRACT ***(Maximum 200 Words)***
This effort entailed the development of an enhanced, handheld, low-cost (less than $1,000 production cost), ultra-sound based Concealed Weapons Detector (CWD), which included the building of a working model for further test and evaluation. Development of inexpensive technology to enable reliable detection of metallic and non-metallic concealed weapons at a standoff distance of up to 10 meters is of great value to law enforcement and security personnel. It was designed for low power operation. The sensor utilizes focused ultrasound (40-kHz frequency) to remotely detect concealed objects from beyond arm's length out to a range of about 25 feet (8 meters). The detector emits an adjustable, audible alarm (with provision for an earphone jack) as well as a visible 5-level LED indicator when an object has been detected. A switchable aiming light allows the user to accurately determine the location of the concealed object. The system was tested on a variety of weapons and clothing types to determine the effectiveness of acoustic phenomenology for detecting weapons concealed beneath a person's clothing. The contractor delivered 20 handheld devices to AFRL for operational effectiveness.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFRL	Air Force Research Laboratory
CWD	concealed-weapons detector
FOV	field of view
FPED	Force Protection Equipment Demonstration
FWHM	full-width-at-half maximum
HCWDD	Handheld Concealed Weapons Detector Development
NIJ	National Institute of Justice
SPIE	The International Society for Optical Engineering

ACKNOWLEDGEMENTS

This final report serves to document the accomplishments of the Concealed Weapon Detector Program (F30602-00-C-204) co-sponsored by the Air Force Research Laboratory (AFRL) and the National Institute of Justice (NIJ). The principle investigator was Dr. Norbert Wild. This effort was a follow-on to an earlier program under which Jaycor developed the first prototype handheld concealed weapon detector. We thank Mr. David Ferris of AFRL at Rome, NY who was the program technical manager and provided assistance and guidance during the course of this effort.

At Jaycor/Titan's San Diego facility, Mr. Steve Niederhaus was responsible for the laboratory testing and directed the manufacture and assembly of the second-generation prototype units. Mr. Hon Lam was instrumental in laying out the electrical schematics and breadboarding the various subcircuits and modifications that were made. Mr. Chris Lum was responsible for the fabrication of the plastic molded parts and other mechanical assemblies as well as assembly and quality control of the final product.

SUMMARY

The Concealed Weapon Detector Program (F30602-00-C-0204) was awarded to Jaycor on 31 July 2000. Technical work on the contract was completed two years later, 31 August 2002, with the delivery of 16 second-generation prototype units to AFRL and NIJ for user evaluation. An additional 4 units were prepared and delivered in September.

The National Institute of Justice (NIJ) and the Air Force Research Laboratory (AFRL) initiated the program in response to requests from various law enforcement agencies across the country for a cost-effective weapons detection system that would be capable of detecting both metallic and non-metallic weapons from a stand-off distance of up to 10 meters. The primary application of these detectors will be to enhance the safety and effectiveness of community police officers around the nation by: 1) establishing reasonable grounds for searches of suspects; 2) scanning suspects for both metallic and nonmetallic weapons at safe stand-off distances during arrests; and 3) searching for both metallic and nonmetallic weapons on cooperative subjects at courthouse entrances and other police-controlled portals.

Building on Jaycor's original prototype design (also sponsored by AFRL and NIJ) the scope of the effort included a number of design modifications that helped to extend the stand-off distance from 12 feet out to 25 feet, reduce the false alarm rate (both false positive and false negative), and make the unit more ergonomically functional.

The program consisted of an initial phase of development and testing, followed by a phase of design, additional testing, fabrication and assembly. A number of formal presentations were made at the annual AFRL/NIJ Program Reviews held during the course of the effort, as well as at the SPIE Conference on Enabling Technologies for Law Enforcement and Security held November, 2000 in Boston, Massachusetts, and the SPIE Aerosense 2002 Conference held in May of this year in Orlando, Florida. A demonstration booth was also set up at the Force Protection Equipment Demonstration (FPED III) held at Quantico Marine Corps Base, Virginia in May, 2001. Figure 1 highlights the program's activities during the course of the effort.

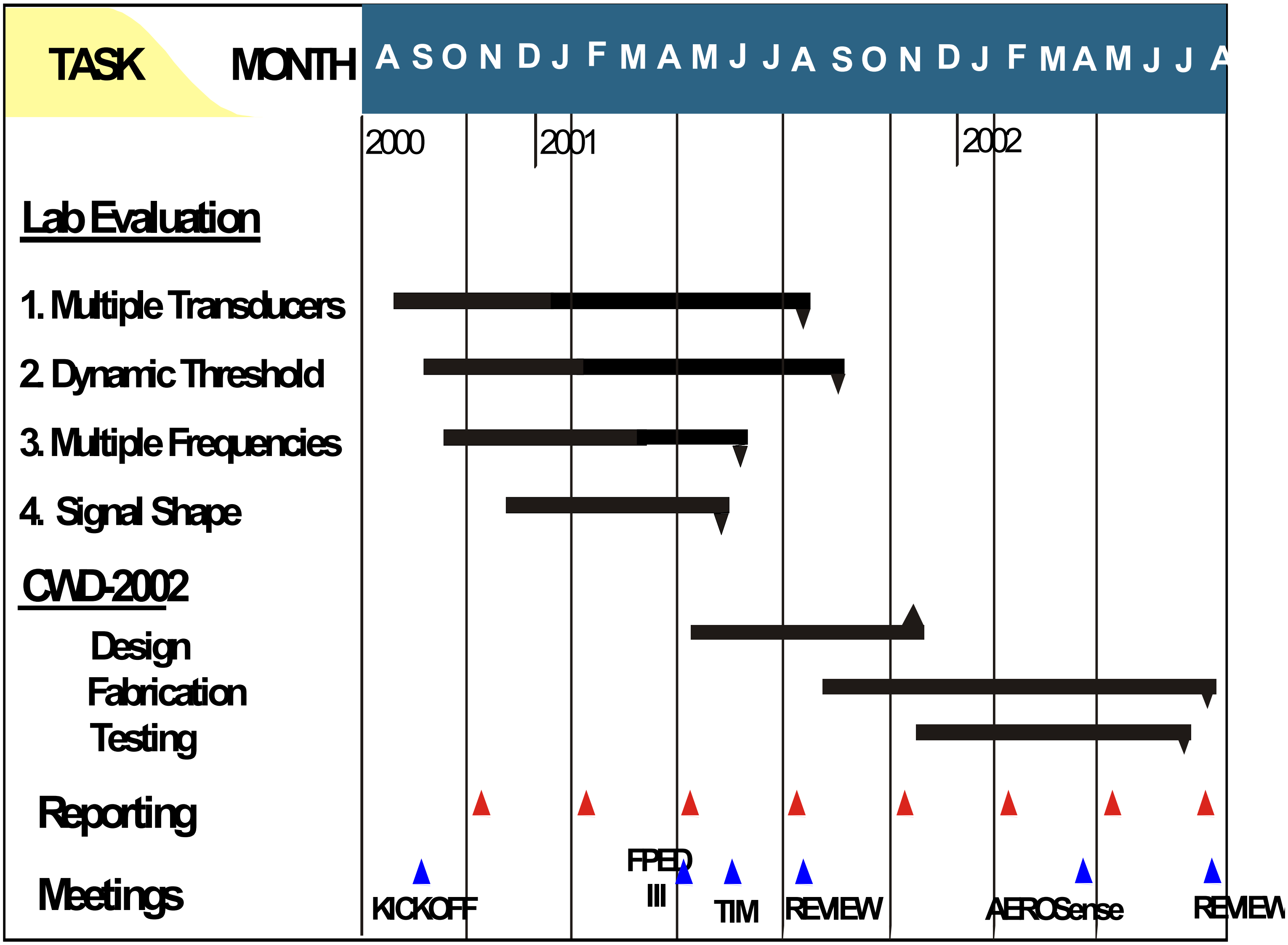

Figure 1. Summary of program activities.

1.0 INTRODUCTION

The goal of the Handheld Concealed Weapons Detector Development (HCWDD) program is to put dramatically improved low-cost, concealed-weapons detector (CWD) prototypes in the hands of law enforcement officers at the community level. The handheld detectors developed under this effort will enable officers to remotely detect both metallic and nonmetallic weapons concealed beneath clothing at ranges up to 25 feet. The primary application of these detectors is to enhance the safety and effectiveness of community police officers around the nation by: 1) establishing reasonable grounds for searches of suspects; 2) scanning suspects for both metallic and nonmetallic weapons at safe stand-off distances during arrests; and 3) searching for both metallic and nonmetallic weapons on cooperative subjects at courthouse entrances and other police-controlled portals.

It is important to note that this detector can not tell the difference between a weapon and an ordinary object such as a cell phone, a bunch of keys, credit cards, etc. However, our philosophy has been that an alarm indicator from a harmless item is preferable to not being able to detect a potentially dangerous weapon. Under this effort, we have improved the signal processing of the device to lower the false-alarm rate and also increased the probability of weapon detection through heavy clothing.

1.1 CONCEALED WEAPON DETECTOR CONCEPT

The CWD-20002 hand-held detector is an outgrowth of a more complex sensor design that was capable of imaging concealed weapons. The first-generation prototypes of the hand-held unit, dubbed the CWD-2000, were designed to simply detect (yes/no), rather than image, concealed objects up to a range of about 12 feet. The detector operates in much the same way as a commercial range finder, but at higher peak acoustic intensities and higher repetition rates. The detector alerts the user to the presence of a concealed object using an audible tone and a visible light-bar indicator. On-board receiver electronics monitor ultrasound glints above a body/clothing background level while compensating for changing range and attenuation.

A photograph of one of the first generation CWD-2000 prototype units is shown in Figure 2. The latest version, developed under this effort and dubbed the CWD-2002, is shown in Figure 3.

The CWD utilizes a 40-kHz ultrasonic transducer element to detect solid objects beneath a variety of clothing material types and operates on a commercially available rechargeable battery. The per-unit cost of the CWD is expected to be less than $500 in small quantities and to approach $300 in large quantities (>1,000).

Figure 2. Photograph of one of the first generation CWD-2000 prototype handheld units.

Figure 3. Photograph of one of the second generation CWD-2002 handheld units.

2.0 METHODS, ASSUMPTIONS AND PROCEDURES

As shown in Figure 1, the effort was roughly divided into two separate phases. The first phase consisted of a series of rigorous laboratory tests and evaluations of proposed improvements to the existing CWD-2000 design. After assessing the results of these tests, those improvements that were seen as truly upgrading the performance of the existing CWD-2000 design were incorporated into a new design for the CWD-2002 sensor. Fabrication, assembly and calibration of a total of 20 units of this finalized design was then undertaken and successfully completed. This section of the Final Report will describe the various proposed upgrades and how they were evaluated in the laboratory. A description of the design, fabrication, and assembly procedures that were employed will also be given here. The results of the laboratory testing on each of the upgrades will be presented in the following "Results and Discussion" section. Four main upgrade activities, as originally proposed, were pursued for the second-generation units (CWD-2002) under this effort. A description of these upgrade activities follows.

2.1. MULTIPLE TRANSDUCERS

With both the initial CWD-2000 design and the CWD-2002, the user must move the detector from side to side and up and down while aiming the sensor at a fixed location on the targeted individual to maximize the viewing angle of the detector and thus increase the probability of detection. This is a result of the relatively narrow field of view (FOV) of the detector/antenna configuration (3-5 degrees). The narrow FOV is necessary to have a spatial resolution on the order of 6 inches (a typical handgun or knife dimension) at a range of 12 feet. If the reflected acoustic energy is not within the FOV, the detector can be pointed at a concealed item and not detect it. Fortunately, most weapons, like handguns, have multiple reflecting surfaces that provide for a broad range of return angles for the ultrasound energy.

The source of the ultrasound used in the sensor is a small (0.5-inch diameter) piezoceramic disc that has a nominal full cone-angle divergence of about 60 degrees. The transducer is mounted at the focus of a 5-inch diameter parabolic dish to generate a collimated ultrasound beam source. The effective full-width-at-half maximum (FWHM) transmitted intensity was measured to be

3.0 degrees for the resulting collimated beam, as shown in Figure 4. This divergence, while small, corresponds to an effective field of view of about 6 to 7 inches on a target at 12-feet range. Thus, the small divergence gives an acceptable spot size at the desired range but also limits the sensitivity of the detector to off-axis reflectance angles. At the extended range of 25 feet, the lateral extent of the FOV for the CWD-2002 is about 17 inches.

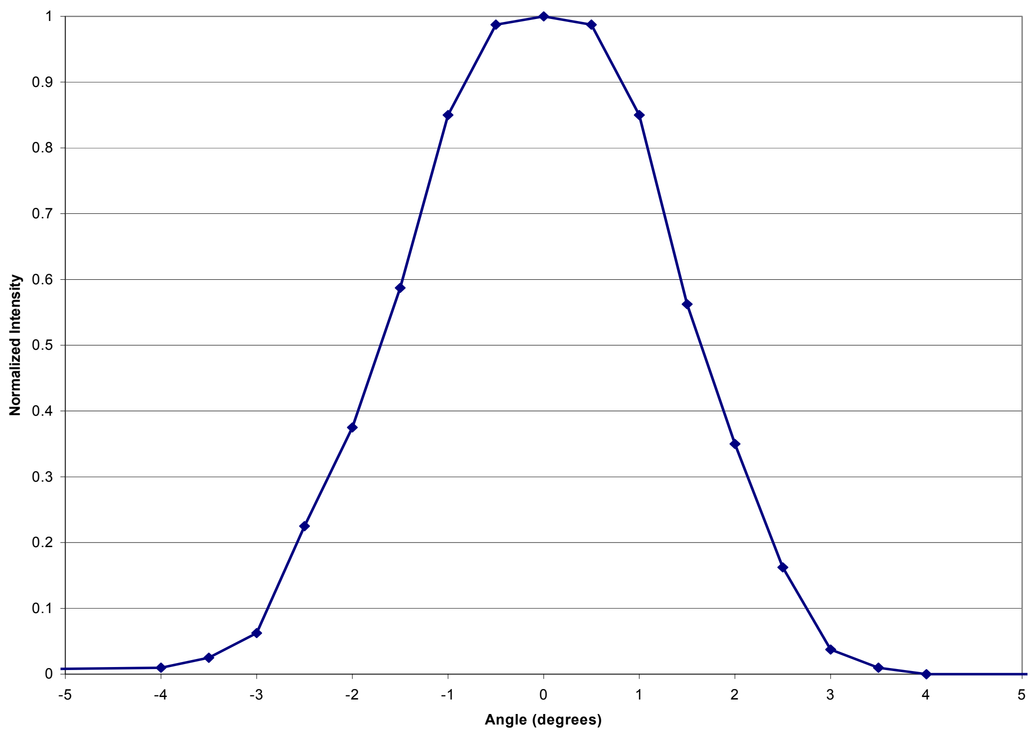

Figure 4. Normalized received intensity of ultrasound beam reflected from a vertical pole vs. angle of pole off central beam axis.

This glint angle sensitivity affects the probability of detection, P_D, because of the chance that the detector will not irradiate a facet of the weapon at near normal incidence (within the FOV of the detector). Since most concealed weapons, like handguns or knives, are carried flat against the body, the best angle for aiming the detector at each spot, therefore, is normal to the body surface. Presently, the most effective way to use the detector is to aim it at locations on the body where weapons are likely to be concealed, and then use lateral and vertical motions of the arm to maximize the range of viewing angles while aiming at the same spot.

Since the range of the angles of incidence of the ultrasound beam on a suspect is limited, it becomes harder to detect objects with increasing range. To alleviate this problem, i.e., to increase the probability of detection, the use of additional transducers was thought to have the potential for effectively increasing the FOV of the detector while maintaining the desired spatial resolution. Additional ultrasound transmitters were installed around the periphery of the existing cylindrical shield cage using two and then four separate transmitters to determine if this approach would be effective. To increase the effective viewing angle even further, a folding support arm for each transducer was also examined. For example, using a 4-inch radial extension arm for each transducer would theoretically increase the viewing angle from the current 3 degrees to about 9 degrees.

These additional transmitters were not collimated (only the central transmitter/receiver was collimated), so their beam patterns were on the order of 3 to 4 feet in lateral extent at distances beyond 10 feet. However, since the receiver was still in a collimated configuration, i.e., looking at a spot on the order of 6 inches diameter, there was little observed interference from reflections outside the existing FOV. The effect is analogous to viewing an object with a microscope and using additional side lighting for increased illumination. There were two problems encountered with these configurations that eventually determined that the addition of extra transmitters was not useful in increasing P_D. First, due to the large divergence of the peripheral transmitters, the power on target (within the field of view) was relatively small when compared to the power being delivered by the collimated co-axial source. Thus, the central collimated source tended to dominate any reflected signal, minimizing the advantage of the additional illumination. Without using rather large and cumbersome collimators on these peripheral transmitters, this approach did not yield any significant increase in the effective field of view. Secondly, there was a problem with constructive and destructive interference between the different transmitters that resulted in erroneous readings when viewing an object at slightly different angles. Detailed results of these investigations are presented in Section 3.1.

2.2. DYNAMIC DETECTION THRESHOLD

In order to enhance the signal-to-noise (or signal-to-clutter) ratio, for a given set of conditions (range, weapon type, and clothing type), a variable or dynamic detection threshold setting was considered. In the previous CWD-2000 design, the threshold for detection was set for an unarmed person wearing a light cotton shirt standing at a range of about 7 feet. For these conditions, only one light (that also serves as the power ON light) on the 5-light LED display was illuminated. The disadvantage of a fixed threshold setting is that for clothing materials with an above-average reflectivity, the total dynamic range of the detector is not utilized and there is a tendency for the number of false-positive alarms to increase.

A dynamic, or variable, detection threshold setting would allow the sensor to adjust its sensitivity according to the type of clothing a suspect is wearing. Operationally, the user would point the detector at several different areas on the suspect (both front and back as the suspect is directed to turn around slowly) and the light bar indicator would show the readings for each area while preserving the dynamic range of the detector. Under this effort, the circuitry for an active or dynamic threshold for detection was intended to sense the average level of reflectance and automatically adjust the low end of the detector to compensate for clothing materials with an above average reflectance. The circuit was not fully developed, however, due to problems with the inherent noise levels present in both the fixed and variable high gain amplifier stages.

2.3 USE OF MULTIPLE AND/OR DIFFERENT FREQUENCIES

The use of ultrasonic frequencies other than 40 kHz was also examined under this effort. Higher frequencies are capable of resolving an object's spatial location more precisely, whereas lower frequencies are able to better penetrate through clothing more readily. A 60-kHz transducer was examined but found to have too high attenuation (about 2.3 dB/m) in air and not enough initial drive power to be useful. A configuration using two transducers with one operating at 40 kHz and the other at 23 kHz was also examined in the hope that increased detectability could be achieved by allowing the 23-kHz energy to better penetrate and detect an object (although with diminished spatial resolution). Using the same collimating optics as in the CWD-2000, the

spatial resolution at 23 kHz was found to be on the order of 10 inches at a range of 10-12 feet. The disadvantage of using two separate frequencies is that it requires a more complicated focusing/collimating configuration since the two sources need to be coaxial or have different, and bulkier, collimating optics. Also, the 23-kHz transducers were much bigger than the 40-kHz elements and did not seem to provide for any significant increase in P_D. Results of these investigations are presented in Section 3.2.

2.4 SIGNAL-SHAPE DISCRIMINATION

A fourth modification to the CWD-2000 design that was considered involved data processing of the return (reflected) signal. During previous efforts, it had been noted that the return pulse is sometimes characterized by a waveform that is dependent upon the shape of the object being detected. With the existing CWD-2000 units, motion of the handheld unit over a target spot also results in temporal changes to return signals, particularly if a hard, reflecting object is present in the target region. After a series of measurements on a variety of two-dimensional targets of different shapes (square, circle, elongated rectangle, etc.) no consistently discernible differences in waveform signature relative to target shape were observed. Details of these results are presented in Section 3.3.

2.5 ADDITIONAL MODIFICATIONS AND IMPROVEMENTS

A number of other upgrades to the CWD-2000 design were investigated and incorporated into the final CWD-2002 design. These include an upgraded receiver amplifier with a lower noise floor and increased gain over the previous design. The drive (transmitter) circuitry was also modified to allow for higher power transmitted pulses to accommodate the increased range requirement. As mentioned earlier, the power circuitry was changed from a 3-battery system to a single battery supply to reduce weight and lessen the complexity of the recharging circuitry. The beam collimator was manufactured from Delrin rather than the previous composite Rinboard material to enhance its long-term stability in the presence of moisture and humidity. The incandescent high power aiming light was replaced by a lower power laser diode to conserve battery power and improve visibility. Four of the 20 units delivered for evaluation were configured with the older incandescent light source for comparison purposes. Ergonomically, the

new design benefits from having the single battery located in the handgrip. In addition, the entire housing assembly is made from a more robust plastic to minimize breakage as a result of normal wear and tear. The interior walls of the housing were lined with an acoustic dampener to minimize spurious noise signals produced from stray reflectances off the housing itself.

2.6 CWD-2002 DESIGN, FABRICATION, AND ASSEMBLY

The results of the laboratory testing were incorporated into an upgraded design for the sensor. A computer-aided design software tool (Solid Works) was used to render the concept upgrade into a form that could be sent out to a commercial mold vendor. The process of stereolithography was used to generate low cost forms that were then used as mold masters that could provide 15-20 parts before degrading past the engineering specifications. Thus, to generate the 20 sensor prototypes, two sets of mold masters were generated using stereolithography. This also allowed fabrication of different colored parts (black in the first run and blue for the second batch). Parts were cast using a high strength ABS-grade plastic for durability and ruggedness. The parabolic collimator was made from Delrin for less weight and its long-term stability and insensitivity to moisture and humidity.

Fabrication of the plastic parts took about 3 weeks. These parts were delivered and assembly began during the month of April, 2002. Additional parts, such as the collimator dish and back-panel display, were delivered during the summer of 2002. Assembly of the tripod-mounted transducer assembly was done in-house with each ultrasonic transducer and laser pointer optically aligned on a precision lathe. Figure 5 shows a photograph of the assembly area in Jaycor's machine shop where the tripod assemblies were configured.

A custom, circular printed circuit board for the 40-kHz drive and high gain receiver electronics was laid out by Jaycor personnel, fabricated by a local vendor, and delivered in July, 2002. The circuit boards were individually populated by hand at Jaycor using predominantly surface-mount parts to minimize weight and electronic noise levels. Each board was then powered up and calibrated before installation in the final assembly. The circuit board is mounted directly behind the Delrin collimating dish using 1/2-inch stand-offs. A photograph of a fully populated board is

shown in Figure 6. Figure 7 depicts the CWD-2002 with one side of the housing removed to show the placement of the circuit board, collimator dish and transducer/laser tripod assembly.

The handheld sensor was designed to take advantage of commercially available battery technology. A rechargeable 7.2-V battery pack rated at 1500 mAh, similar to those used in commercial hand tools, was selected as the power source for the sensor. All of the evaluation CWD-2002 units were delivered with a charger unit (110 VAC to DC converter) and a rechargeable battery pack. The previous prototype incorporated 3 separate battery packs that made for a heavier sensor and also added complexity (and more parts) to the charging circuitry. Figure 8 shows a photograph of the battery and charger unit.

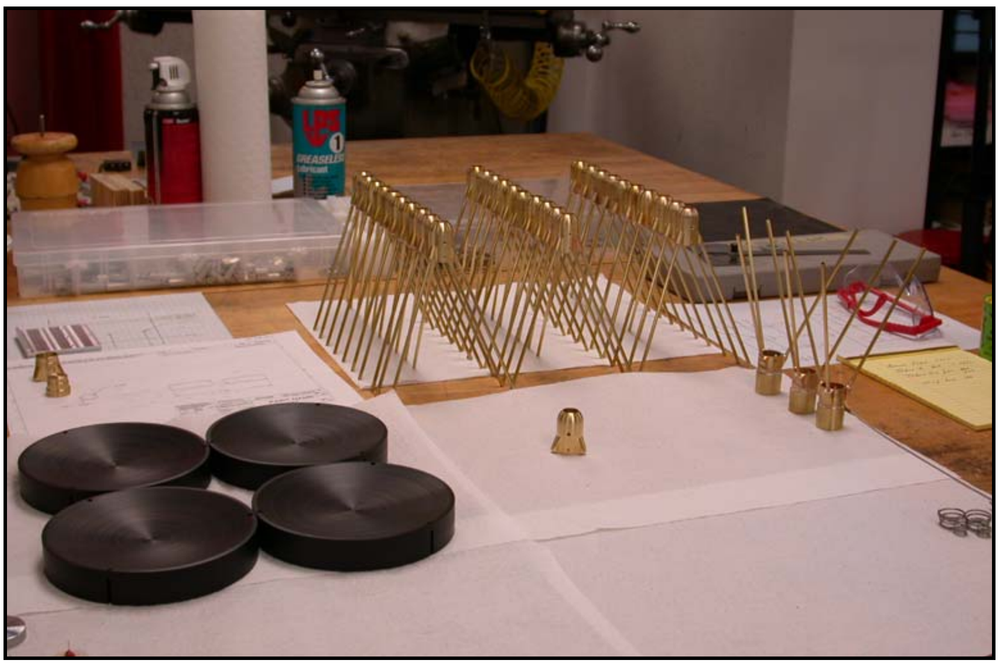

Figure 5. Tripod assemblies being readied for installation. The tripod holds both the ultrasonic transducer and the laser diode aiming light. Also visible in the foreground are four of the Delrin collimating dishes. The tripods are mounted on the Delrin dish with the transducer positioned at the focal point.

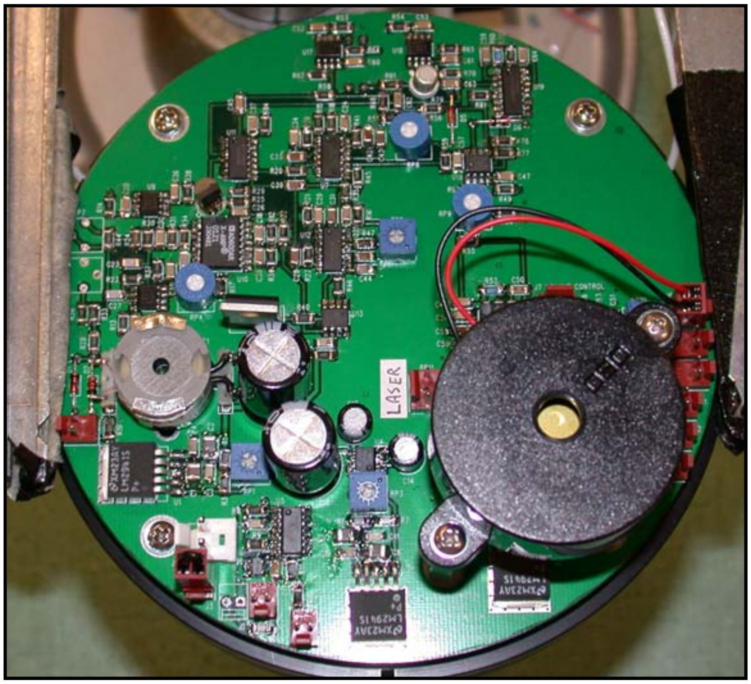

Figure 6. A fully populated circuit board before installation into the CWD-2002 housing.

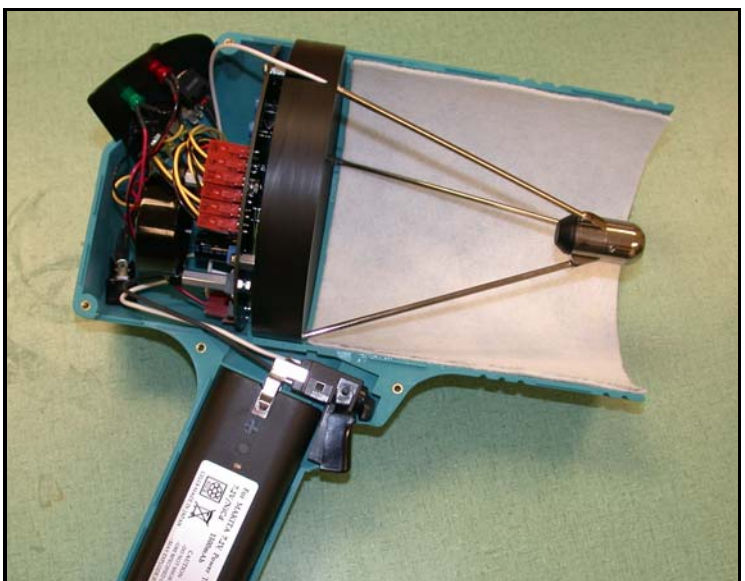

Figure 7. Side view of CWD-2002 with right housing removed to show placement of the electronic circuit board, collimating dish and transducer/laser pointer assembly.

Figure 8. Rechargeable battery pack and charging unit with battery in charge position.

3.0 RESULTS AND DISCUSSION

This section of the Final Report will present the results of the various proposed improvements to the sensor design. A discussion of these results and an assessment of the performance of the resultant CWD-2002 design in terms of the probability of detection and false alarm rate will also be presented.

3.1 RESULTS OF THE INVESTIGATION OF MULTIPLE TRANSDUCERS

As discussed in Section 2.1, the use of multiple ultrasonic transducers was originally proposed as a means of increasing the effective field of view of the receiver. A series of tests was performed on a variety of transducer configurations to determine if this would be effective. As shown in Figure 9, a testbed was set up in the laboratory to allow for rapid reconfiguration of transducer spacing and relative position. Up to four separate transducers (in addition to a central axis transducer) could be deployed and monitored independently. The off-axis radial position of each transducer could also be adjusted to determine the effects on sensitivity and detectivity.

Figure 9. Photograph of the laboratory testbed used for investigating the effects of using multiple transducer elements on the sensitivity of the CWD sensor.

The testbed was calibrated by checking that the received signal (on-axis) from each off-axis transducer was similar and that the digital superposition of all four separate signals was the same as the resultant signal obtained when driving all four simultaneously. This data is shown in Figure 10 using an unconcealed polycarbonate knife as a target at a range of 12 feet.

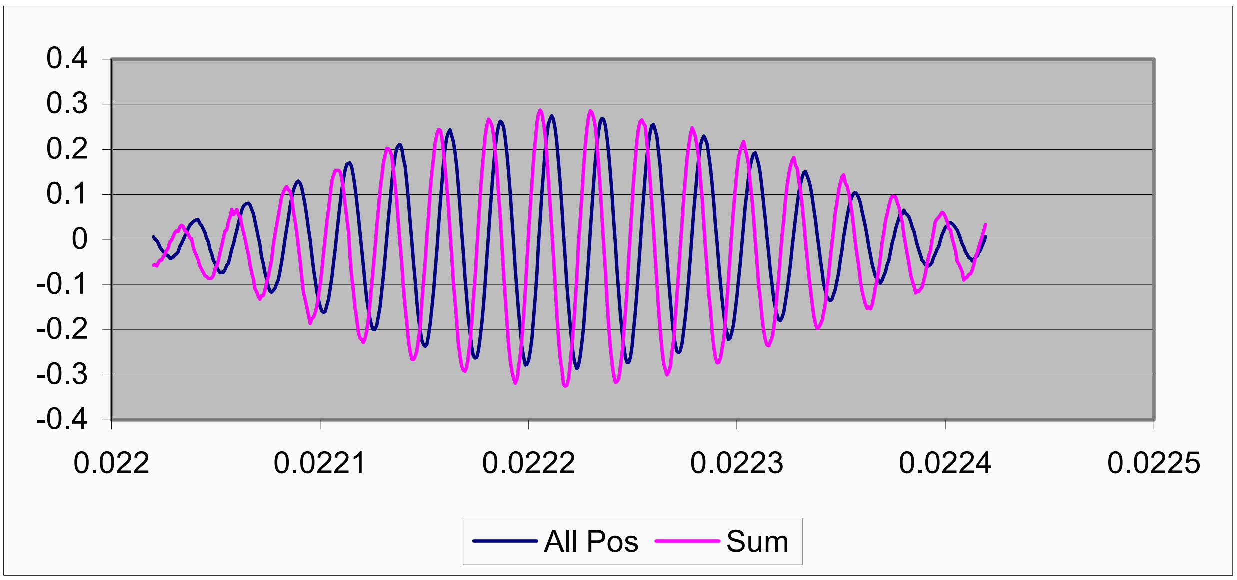

Figure 10. Plot of the measured received signal (blue trace) obtained with four off-axis transmitters compared to the digital sum (fuschia trace) of four separate signals.

Representative data plots are shown in Figures 11 and 12 for two and four additional off-axis transmitters, respectively. In Figure 11, one can see that the field of view of the detector has increased somewhat from the nominal 3 degrees to about 6 degrees. However, there is a noticeable null at zero degrees due to destructive interference between the two off-axis transmitters. This was the main problem encountered when using multiple transmitters. In Figure 12, data is shown comparing the received signal for two and four additional transmitters. As expected, the return power increases linearly with the number of additional transmitters. For this configuration, however, there was no obvious increase in the field-of-view angle.

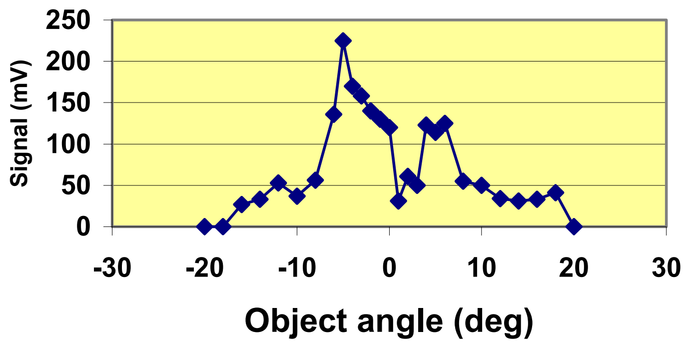

Figure 11. Plot of measured return signal from unconcealed handgun using two off-axis transmitters spaced 9 inches apart (4.5-inch radius). Object angle refers to the angle of the handgun normal (at right angles to the gun barrel) relative to the source transmitter axis.

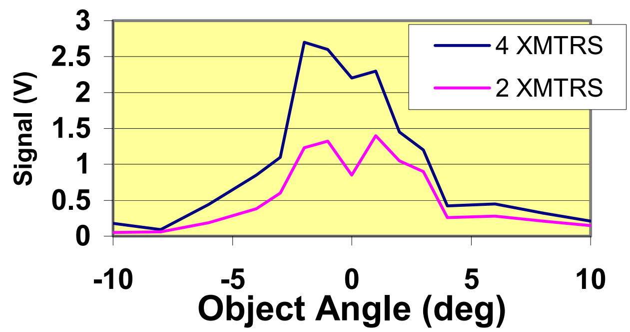

Figure 12. Plot of measured return signals from an unconcealed handgun using two and then four off-axis transmitters spaced 12 inches apart (6-inch radius). Object angle refers to the angle of the handgun normal (at right angles to the gun barrel) relative to the source transmitter axis.

As a result of these tests, it was determined that the use of additional off-axis transmitters does increase the amount of return energy entering the on-axis receiver's field-of-view. However, beyond a range of 10-12 feet, the central on-axis source dominates the return signal due to its narrow divergence (it is collimated) compared to the uncollimated divergence (+/-15 degrees) of the off-axis transmitters. This effect thus minimizes any advantage gained by the presence of the off-axis transmitters. In addition, the observations of destructive interference for certain viewing angles also precludes the use of off-axis transmitters.

3.2 RESULTS OF THE INVESTIGATION OF MULTIPLE AND/OR DIFFERENT FREQUENCIES

As presented in Section 2.3, it was proposed that the use of multiple or different frequencies (other than 40 kHz) should be examined to determine whether there would be any advantage in using a different configuration or scanning frequency. With regards to alternative frequencies, the thought was that lower frequencies would have better penetration through heavy clothing while higher frequencies would be able to better resolve objects spatially at long range. Obviously, frequencies in the audible range (<20 kHz) would not be desirable. So, a series of tests were undertaken to compare the transmittance of 40-kHz ultrasound with 23 kHz. The frequency of 23 kHz was chosen as there was a commercially available transducer at this value. Figure 13 shows a plot of the data obtained for the two different transducers for five different clothing types. As can be seen, there were no dramatic differences between the transmittance values of the two frequencies (less than 15% difference) for any of the clothing types examined. Indeed, the 40-kHz results were comparable or even better than at 23 kHz for types 2-5 (although these were within the measurement error). Since, the 23-kHz transducers are more than twice as large physically as the ½-inch diameter 40-kHz transducers, a decision was made to continue using the 40-kHz transducers. In addition, if one wanted to use 23-kHz transducers, a larger collimating dish would be required to accommodate the large wavelength and still maintain the desired low divergence beam specification.

- **Types of Cloth**

1=No cloth
2=Shirt
3=Sweater
4=Shop coat
5=Flannel shirt
6=Heavy jacket

Figure 13. Plot of measured double-pass return signals from a flat plate for various clothing types using 23- and 40-kHz transducers.

As mentioned previously, on the high frequency side, a 60-kHz transducer was examined and found to have much higher attenuation in air compared to the 40-kHz ultrasound (2.3 dB/m compared to 0.2 dB/m). Thus, no further investigation into higher frequency transducers was undertaken.

With regards to a configuration employing separate transducers at different frequencies, a brief study of the mechanical layout for such an arrangement was made. A configuration using two transducers with one operating at 40 kHz and the other at 23 kHz was examined. Using the same collimating optics as in the CWD-2000, the spatial resolution at 23 kHz was found to be, as expected, on the order of 10 inches at a range of 10-12 feet. While potentially providing some nominal improvement in clothing penetration at 23 kHz, the disadvantage of using two separate frequencies is that a much more complicated focusing/collimating configuration is required since the two sources need to be coaxial or have different, and bulkier, collimating optics. In light of the previously presented results on clothing penetration, it was decided to not pursue a multi-frequency sensor configuration.

3.3 RESULTS OF THE INVESTIGATION OF SIGNAL SHAPE DISCRIMINATION

As discussed in Section 2.4, there was some earlier anecdotal evidence of a correlation in the shape of the return signal envelope and the shape of the target, e.g., gun vs. knife. A series of controlled laboratory tests were undertaken to determine if there was any definitive relationship between the shape of the return ultrasound pulse waveform and the shape of the reflecting target. In addition to the various weapons that were examined (knives and handguns), a variety of generic targets were also fabricated (flat plate, cylinder, round plate, sphere) and evaluated for their return signal properties.

Figures 14 through 17 show some of the return signal waveforms that were obtained during the course of this test series. These data were obtained at a range of 12 feet using a single 40-kHz transducer. With the exception of spherically shaped targets, most of the targets generated return waveforms that were relatively indistinguishable from one another. As shown in Figure 18, the shape of the return waveforms was dominated by the transfer response of the high gain receiver

amplifier. In addition, the inherently high Q of the piezoceramic transducer element also precluded deriving any distinguishable characteristics from the return signal.

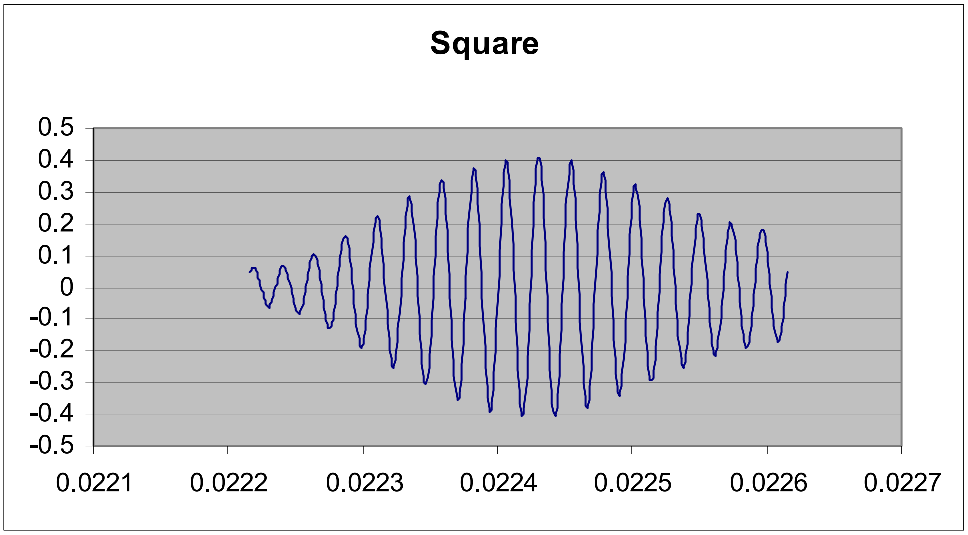

Figure 14. Measured return waveform from a 6-inch square wooden flat at a range of 12 feet. The horizontal axis is time in seconds and the vertical axis is signal am.

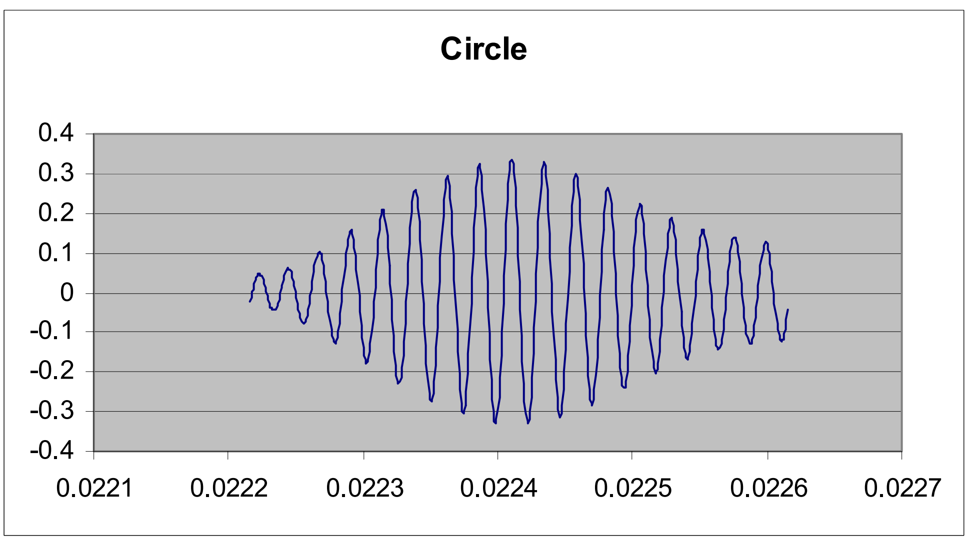

Figure 15. Measured return waveform from a 6-inch diameter wooden flat at a range of 12 feet.

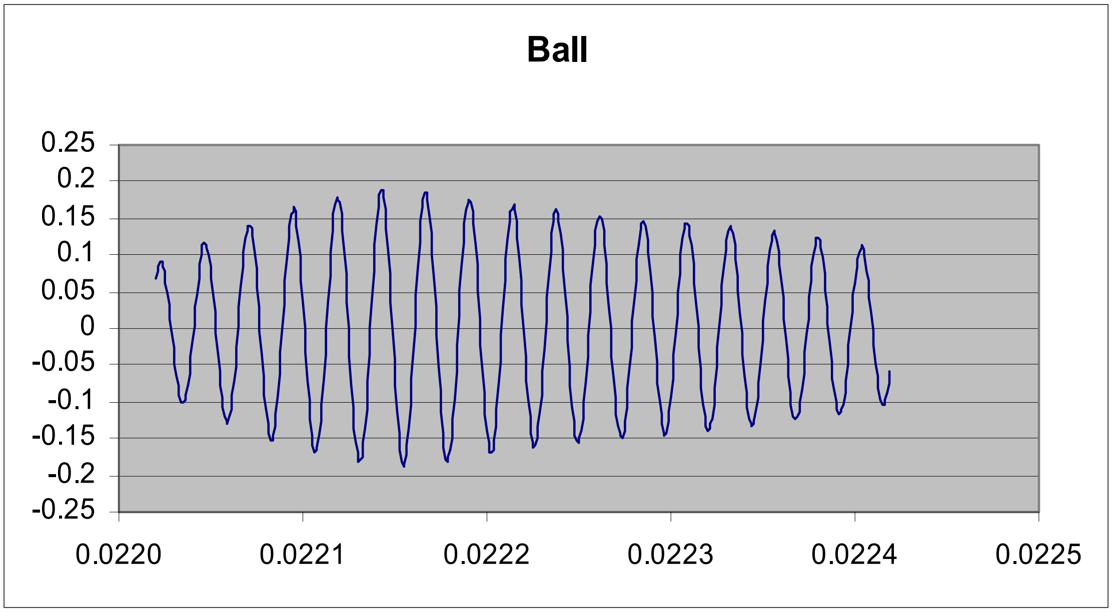

Figure 16. Measured return waveform from a 6-inch diameter plastic sphere at a range of 12 feet.

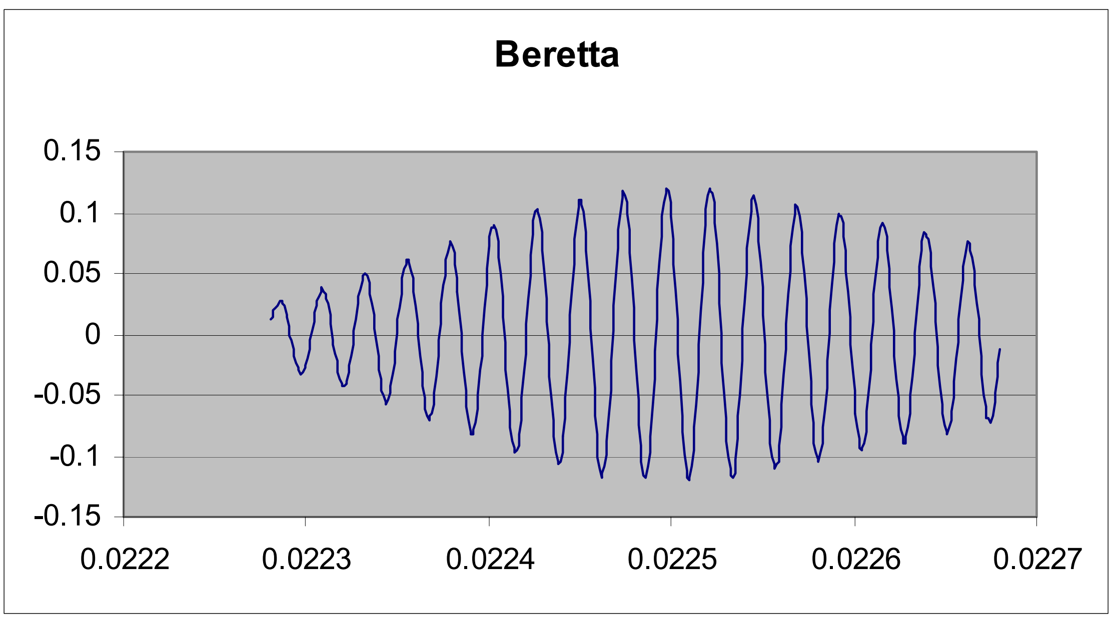

Figure 17. Measured return waveform from an unconcealed Beretta handgun (side-on aspect) at a range of 12 feet.

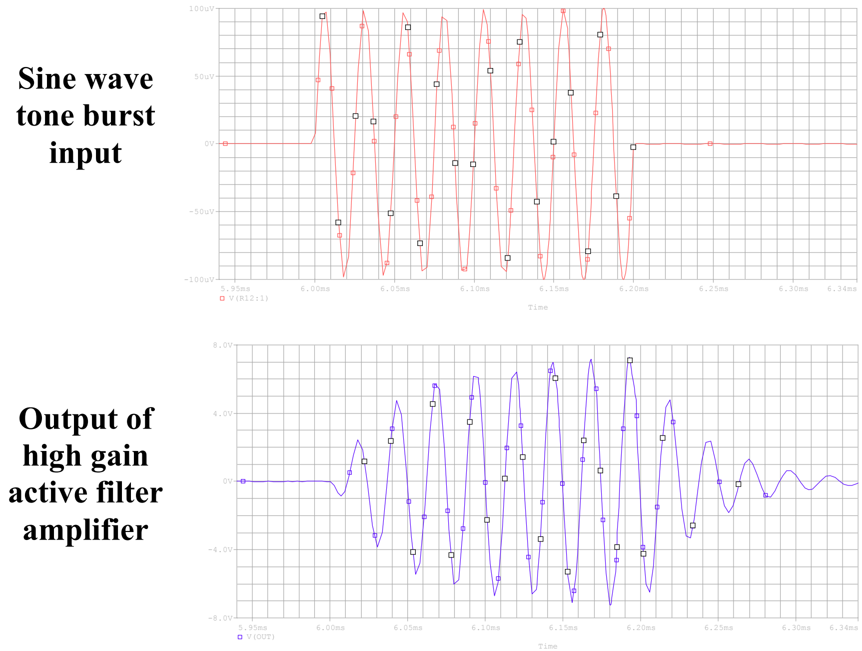

Figure 18. Plot of measured response of high gain electronic amplifier to sinusoidal input tone burst (8 cycles of 40 kHz frequency).

Additional scans were also made of weapons in front of a mannequin (soft rubber) to determine the effect of the presence of an adjacent background on the return waveform. Figure 19 shows a representative trace taken with and without a handgun present in front of the mannequin. With no handgun present, the return signal from the mannequin itself was comparable in shape and magnitude to the signal from the handgun by itself. When the handgun was placed in front of the mannequin, the compound return signal was noticeably different, but there was never any systematic and consistent shape to the return signals of multi-object targets, as might be present in real-life operating situations. The end result of the analysis of these test measurements was that signal shape discrimination would most likely not be an effective means of determining whether a detected object was or was not a weapon. A source capable of generating a single cycle high intensity pulse (that presently does not exist) might be capable of providing such information, similar to object discrimination in radar applications, but the development of such a source was beyond the scope of this effort and was not pursued further.

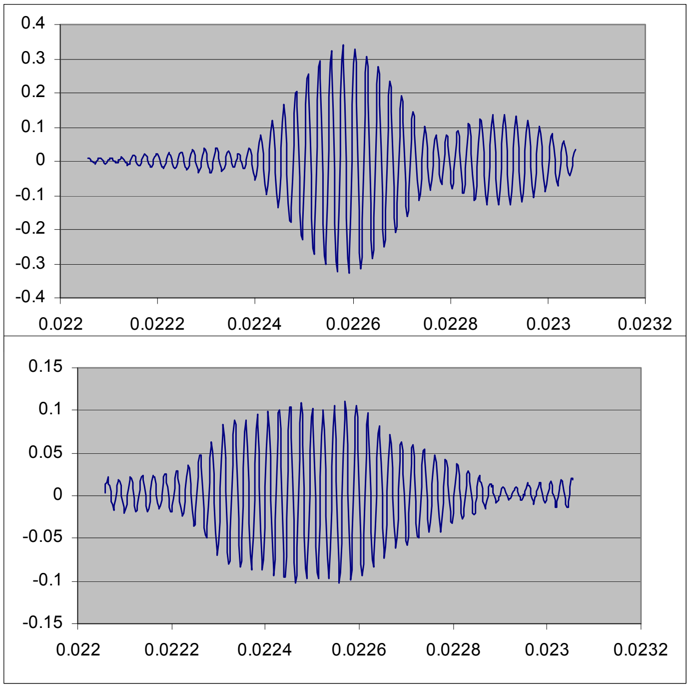

Figure 19. Plots of measured return waveforms for an unarmed mannequin (top trace) and with a Beretta handgun directly in front of the mannequin (bottom trace). Horizontal axis is time in seconds and vertical axis is signal amplitude in volts.

3.4. RESULTS OF EXTENDING THE EFFECTIVE RANGE

The previous sensor (CWD-2000) was capable of detecting concealed objects out to a maximum range of about 12 feet (4 meters). One of the main goals of this effort was to extend the detection range out to 25 feet, or even 30 feet (10 meters), if possible. To achieve this objective, two aspects of the sensor electronics were modified: the transmitter output pulse and the receiver amplifier. By increasing the drive level of the output transmitter, more ultrasound energy can be delivered to the target and subsequently more return energy can be received. By increasing the gain of the receive amplifier, without increasing the noise level, the ability to detect small signals at maximum range was also increased.

The previous CWD-2000 sensor was limited in its drive amplitude as a result of breakdown in the step-up transformer that was used to generate the high voltage pulse train. There was also some limitation due to the rated current capacity of the transistor switch that was used to

generate the input pulse to the transformer. A new transformer was designed and fabricated by an outside vendor and found to be capable of driving 350 V_{pp} (peak-to-peak) bursts without breaking down. This new transformer was then incorporated into a redesigned output pulse drive circuitry. As part of the redesigned circuit, a more robust transistor switch was selected and incorporated into the circuit. Output waveforms were then measured and found to be a factor of 4 greater in amplitude than previously seen. Figure 20 shows a plot of the measured return peak amplitude as a function of range for the CWD-2000 drive circuitry compared to the increased CWD-2002 levels.

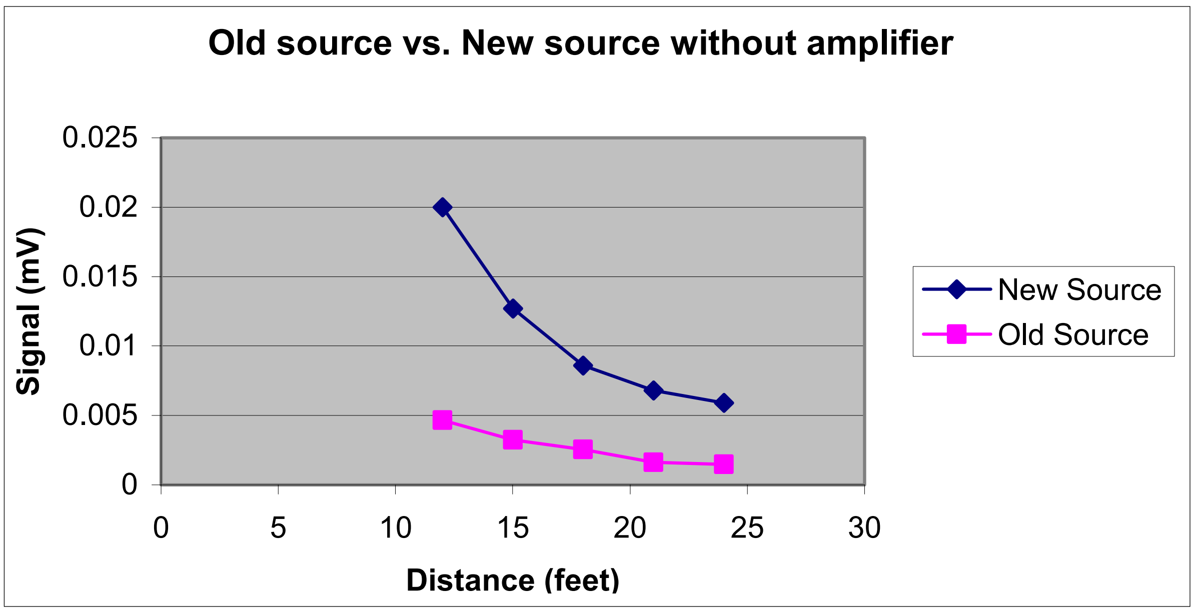

Figure 20. Plot of measured return signal amplitude for old (CWD-2000) and new (CWD-2002) pulse transmitter. Minimum detectable signal is about 5 mV.

In order to take advantage of the increased output amplitude of the transmitter, the high gain receive amplifier was also modified. The 40-kHz active tuned filter was redesigned using low power, single supply amplifiers and fabricated using surface mount components to minimize noise levels. The measured signal gain was then seen to have lower noise levels than the previous version while yielding a higher gain (35,000 vs. 25,000). This circuit design was then incorporated into the CWD-2002 circuitry.

3.5 ASSESSMENT OF THE PROBABILITY OF DETECTION, P_D

After finalizing the design for the electronics, circuit boards were fabricated, populated with parts and then calibrated. Prior to full scale assembly of the 20 evaluation units, two units were assembled and characterized for their ability to detect a variety of objects at various ranges. These results were then compared with those obtained using one of the older CWD-2000 units. The objects that were used as targets included a cell phone, a Beretta handgun, a polycarbonate knife, a folding-type pocket knife, and a simulated (wooden) handgun. Comprehensive measurements were made at ranges of 6, 12 and 18 feet. A variety of clothing types were utilized in the study. These included a cotton flannel shirt, a polyester shop coat, a woolen suit jacket and a cotton/polyester sweatshirt. Volunteer employees were used to conceal each object and the individuals were then scanned with the CWD sensor at three different aspects: front-on, side-ways, and backside. The target object was always positioned on the front of the individual, above the waistline and below the neck.

The results of this study are summarized in Figures 21 and 22. Figure 21 contains the results using the CWD-2000 unit, while Figure 22 summarizes the data obtained using the new CWD-2002 units. The tables are color-coded to indicate the level of detection and correspond to the illuminated indicator levels used on the CWD sensor. Green indicates no detectable signal above background and corresponds to the first level on the CWD sensor. Yellow indicates a signal above threshold and corresponds to the second and third levels on the CWD sensor (these have been made explicitly yellow on the CWD-2002 units). Red indicates a large return signal and corresponds to the fourth and fifth levels on the CWD sensor (these are illuminated red on the CWD-2002 units).

No Cloth 6 ft away			
	Cell phone	Beretta	Pocket knife
Front	5	5	3
Side	2	3	3
Back	2	2	2
Flannel Shirt			
Front	4	5	3
Side	2	3	1
Back	2	1	1
Shop coat			
Front	3	4	2
Side	2	4	2
Back	2	2	2

No Cloth 12 ft away			
	Cell phone	Beretta	Pocket knife
Front	3	4	1
Side	2	2	1
Back	1	1	1
Flannel Shirt			
Front	3	2	2
Side	2	2	1
Back	1	1	1
Shop coat			
Front	3	4	2
Side	2	3	2
Back	2	2	2

No Cloth 18 ft away			
	Cell phone	Beretta	Pocket knife
Front	1	2	1
Side	1	1	1
Back	1	1	1
Flannel Shirt			
Front	1	1	1
Side	1	1	1
Back	1	1	1
Shop coat			
Front	3	2	2
Side	2	2	2
Back	2	2	2

Figure 21. Assessment of the probability of detection using the previous CWD-2000 sensor system.

No Cloth 6 ft away			
	Cell phone	Beretta	Knife
Front	5	5	5
Side	2	3	3
Back	2	2	2
Flannel Shirt			
Front	5	5	5
Side	2	2	1
Back	1	1	1
Shop coat			
Front	5	5	5
Side	2	2	2
Back	2	2	2

No Cloth 12 ft away			
	Cell phone	Beretta	Knife
Front	5	5	5
Side	2	2	1
Back	2	2	2
Flannel Shirt			
Front	4	5	5
Side	2	2	1
Back	1	1	1
Shop coat			
Front	4	5	5
Side	2	2	2
Back	2	2	2

No Cloth 25 ft away			
	Cell phone	Beretta	Knife
Front	4	5	4
Side	1	1	1
Back	2	2	2
Flannel Shirt			
Front	3	5	4
Side	1	2	1
Back	1	1	1
Shop coat			
Front	3	5	4
Side	2	2	2
Back	2	2	2

Figure 22. Assessment of the probability of detection using the new CWD-2002 sensor system.

From Figure 21, for the CWD-2000 unit, there were a total of 6 false negatives out of 27 (22%) frontal orientations over the range of 6 to 18 feet. A false negative is a green light (level 1) or yellow light (level 2 or 3) indicator when there is a weapon present. We have noted that after some experience in using the detector, level 3 (yellow light) indicators are often associated with concealed objects. However, in this assessment, only level 4 and 5 (red light indicators) are considered to be strong probable indicators of a concealed object. From Figure 22, for the CWD-2002 units tested, only 1 false negative (3.7%) was seen (cell phone at a range of 18 feet) out of the 27 different frontal configurations. This decrease in the false negative rate is due to the higher power transmitter and the enhanced receive electronics as discussed previously. As expected, there was no demonstrated ability to see through a person and detect a concealed object while the individual was turned away from the sensor. This also held generally true for side-on illumination as well. Thus, to be effective, a scan must involve a voluntary rotation of the individual while the operator scans that person to ensure that the front, back and sides are included in the scan.

The occurrence of false positives, i.e., a level 4 or 5 indicator (red light) when no concealed object is present, is an issue that depends primarily on the type of clothing worn by the individual. False positives were observed predominantly when the person was wearing a thick or heavy material such as leather, or with nylon-shell parka jackets. There was no observed change in the rate of false positives at ranges less than 12 feet when comparing the CWD-2000 and the CWD-2002. Since the CWD-2002 can now operate out beyond 12 feet to a maximum useful range of 25 feet, we have now observed false positives out to this range as well. The rate of false positives depends entirely on the type of clothing. For relatively transparent materials (cotton, wool, polyester) the observed rates are below 10%. For reflective materials like leather, rates as high as 80% were observed. Thus, in addition to having the individual cooperate by rotating slowly while being scanned, if they are wearing a heavy jacket, this must be removed for the scan to be effective.

4.0 CONCLUSIONS

The main objective of the CWD program is to put improved CWD sensors into the hands of local law enforcement. At the end of this effort, 20 second-generation units (CWD-2002) were delivered for evaluation and field use. The principal goal is to develop a product that will eventually be demanded by law enforcement officers for protection against weapon attacks and to enhance their own effectiveness. The need for concealed-weapons detection by community law enforcement already exists. By developing the CWD-20002 sensor system, our aim is to provide an effective solution in a low-cost, handheld package that will come to be considered by officers to be as indispensable as body armor.

A number of presentations were made during the course of this effort at various Program Review meetings and public forums such as the SPIE Conferences held annually with regards to law enforcement technology. Copies of the two papers generated during the course of this effort and published by the SPIE are included in the Appendices for reference. Also included is a copy of the last Program Review briefing made at Ft. Belvoir on August 6, 2002, as well as copies of the quarterly Progress Reports. A short Operation and Instruction Manual was also generated and is included here as well. It is felt that to properly and effectively utilize the CWD-2002 sensor. Some level of hands-on training is needed prior to using the device in the field.

APPENDIX A: HANDHELD ULTRASONIC CONCEALED WEAPON DETECTOR

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ABSTRACT

A handheld, battery-operated prototype of a concealed weapon detector (CWD) has been built and tested. Designed to detect both metallic and non-metallic weapons, the sensor utilizes focussed ultrasound (40 kHz frequency) to remotely detect concealed objects from beyond arm's length out to a range of about 12 feet (4 meters). The detector can be used in prison settings, by officers in the field to allow for stand-off frisking of suspects, and to supplement security at courthouse entrances and other monitored portals. The detector emits an audible alarm (with provision for an earphone jack) as well as a visible light-bar indicator to the user when an object has been detected. A high intensity aiming light, with momentary switch, allows the user to accurately determine the location of the concealed object. A follow-on program to the initial development effort is aimed at increasing the probability of detection, reducing the false-alarm rate, and extending the range of detectability out to 30 feet. Plans for accomplishing these tasks will be presented together with data showing the effective range and probability of detection for the present system.

Keywords: Ultrasound, concealed weapon, detector, handheld, nonmetallic

1. INTRODUCTION

This paper describes an ongoing effort to develop a handheld device for detection of both metallic and non-metallic concealed weapons using ultrasonic technology. Jaycor is currently developing, under government sponsorship, a hand-held ultrasonic device capable of concealed weapon detection for use by law enforcement and security personnel. Under contract to the National Institute of Justice (NIJ), several prototype units have been fabricated and delivered for evaluation to the Air Force Research Laboratory in Rome, NY. The handheld device has been shown to be effective at detecting both metallic and non-metallic concealed weapons at distances up to 12 feet [Ref. 1-3].

As a result of the successful prototype development program, a follow-on effort for enhancing the detector's ability to see through a wider range of clothing material types was recently initiated. Presently, the prototype detector is somewhat limited as to its ability to "see" through heavy clothing such as leather jackets and winter parkas which have a relatively high reflectance for the ultrasound waves emitted by the device. In its present state, the device is most effective when viewing objects under woven materials such as sweatshirts, sweaters, wool suit coats and the like.

Jaycor envisions the application of the concealed weapon detector (CWD) to be optimal for remote pat-downs to better prepare officers before moving in to do a hands-on search that would still be required. As such, the detector could provide "probable cause" for performing a more intensive search of a suspect. In addition, just pointing the detector with its bright aiming light at a suspect can elicit behavioral changes that an experienced officer could observe.

It should be emphasized that the detector can not readily distinguish between weapons and ordinary objects such as belt buckles, bunches of keys, plastic credit cards etc. which can trigger false alarms. However, our philosophy has been that a false alarm from a harmless item is preferable to not being able to detect a potentially dangerous weapon. As part of the current follow-on effort, we plan on improving the signal processing of the device to lower the false-alarm rate and increase the probability of weapon detection through heavy clothing.

Product availability will depend to a large degree on the outcome of this upgrade effort. We presently see these devices becoming commercially available in the early 2002 time frame with a projected price of less than $500. The ultimate goal is an affordable, hand-held, stand-off weapon detection device.

2. CONCEALED WEAPON DETECTOR CONCEPT

The hand-held detector is an outgrowth of a more complex sensor design that was capable of imaging concealed weapons. The first-generation prototypes of the hand-held unit, dubbed the CWD-2000, were designed to simply detect (yes/no), rather than image, concealed weapons up to a range of about 12 feet. The detector operates in much the same way as a commercial range finder, but at higher peak acoustic intensities and higher repetition rates. The detector alerts the user to the presence of a concealed object using an audible tone and a visible light-bar indicator. On-board receiver electronics monitor ultrasound glints above a body/clothing baseline and compensate for changing range and attenuation. A photograph of one of the CWD-2000 prototype units is shown in Figure 1.

Figure 1. Photograph of one of the CWD-2000 prototype units.

2.1. Prototype Features and Technical Specifications

The prototype CWD-2000 has a number of operating features that will be carried over into the improved CWD units. The prototypes utilize a single 40-kHz ultrasonic transceiver and can detect concealed weapons (either metallic or nonmetallic) at distances up to 12 feet away through a limited set of clothing material types on a stationary individual. The ultrasonic beam pattern of the detector is a circular spot about 7 to 12 inches in diameter at ranges from about 3 to 12 feet. Presently, the CWD-2000 units work reasonably well at finding objects between 3 to 12 feet in front of the detector, with the highest probability of detection from 4 to 7 feet. It does not work at all closer than about 3 feet due to a range-gating feature that isolates the sensitive receiver electronics from the large transmit pulse. The CWD-2000 presently has very limited capabilities beyond 20 feet. One of the goals under the current effort is to extend this range out to 30 feet.

In operation, the detector should be aimed first at areas of clothing where weapons are likely to be concealed, including, of course, any obvious bulges in clothing. Once pointed at an area, the detector is then moved from side to side and up and down, using the aiming light to keep the detector pointed at the spot of interest. The side to side and up and down motion of the detector allows it to view the spot from a wider range of angles, increasing the probability of detection.

As the user inspects the suspect, when an alarm sounds, the user should then return to the area that produced the alarm and concentrate a search there to determine the view angle that gives the strongest alarm. Level 4 or 5 alarms (as shown on the LED light bar) are strong indications of a concealed object. For precise aiming, a focussed 5-W halogen lamp allows the user to determine where on a person the detector is pointed. As a side benefit for law enforcement, the high-intensity light can also be used as a spotlight or to temporarily dazzle a suspect. The weapons detector and aiming light can be used independently and are powered by separate, rechargeable battery packs. An audible alarm, normally heard through the rear-mounted speaker, can be optionally heard using an earphone jack which mutes the speaker when in use. An adjustable knob on the

back of the detector controls the loudness of the speaker and earphone. The tone is designed to increase in pitch and intensity as a function of increasing received signal level. A visible alarm indicator in the form of a 5-level light bar on the back of the detector housing shows the relative intensity of the received signal. The lowest level is used as a power ON indicator (with trigger pressed). The detector is designed to look for concealed weapons as long as the trigger is pressed.

2.2. Prototype Upgrade Activities

There are four upgrade activities planned for the CWD-2000 under the current effort. After completion of this design upgrade and testing phase, the validated upgrade designs will be incorporated into a next-generation CWD-200 detector. Under the current effort, 20 functional CWD-2001 units will be fabricated and tested prior of delivery to AFRL for further field testing and evaluation. A brief description of each upgrade activity follows.

2.2.1. Multiple transducers

With the present design, the user must move the detector from side to side and up and down while focussing on a fixed spot to maximize the viewing angle of the detector and thus increase the probability of detection. This is a result of the relatively narrow field of view (FOV) of the detector/antenna configuration (3 degrees). The narrow FOV is necessary to have a spatial resolution on the order of 6 inches (a typical handgun or knife dimension) at a range of 10 feet. If the reflected acoustic energy is not within the FOV, the detector can be pointed at a concealed item and not "see" it. Fortunately, most weapons, like handguns, have multiple facets that generate their own specular reflection.

A 5-inch diameter parabolic dish is used to collimate the diverging ultrasound beam source. The effective full-width-at-half maximum (FWHM) received intensity using a vertically oriented cylinder was measured to be 3.0 degrees as shown in Fig. 2. This divergence, while small, corresponds to an effective field of view of about 6.5" on a target at 10 feet range. Thus, the small divergence gives an acceptable spot size at the desired range but also limits the sensitivity of the detector to off-axis glint angles. Note that at the 30-foot range goal, the lateral extent of the FOV is about 19 inches.

This glint angle sensitivity reduces the probability of detection because of the chance that the detector will not irradiate a facet of the weapon at near normal incidence (within the FOV of the detector). Most nearly flat concealed weapons, like handguns or knives, are carried flat against the body. The most productive angle for aiming the detector at each spot, therefore, is normal to the body surface. Presently, the most effective way to use the detector is to aim it at locations on the body where weapons are likely to be concealed, and then use lateral and vertical motions of the arm to cover a range of angles about the normal while aiming at the same spot.

The range of angles of incidence of the ultrasound beam on a suspect is limited. If only the arm holding the detector is moved, the range of angles of incidence is reduced about inversely as the range to the suspect is increased. For this reason, finding a concealed weapon becomes nearly impractical for the detector beyond about 12 feet, and nearly impossible beyond about 20 feet. To alleviate this problem, i.e., to increase the probability of detection, the use of additional transducers has the potential for effectively increasing the FOV of the detector while maintaining the desired spatial resolution. We propose to install 2 to 4 additional ultrasound transmitters around the periphery of the existing cylindrical shield cage. To maximize the effective viewing angle, a folding support arm for each transducer will also be examined. For example, using a 4-inch extension arm for each transducer would theoretically increase the viewing angle from the current 2 degrees to about 8 degrees.

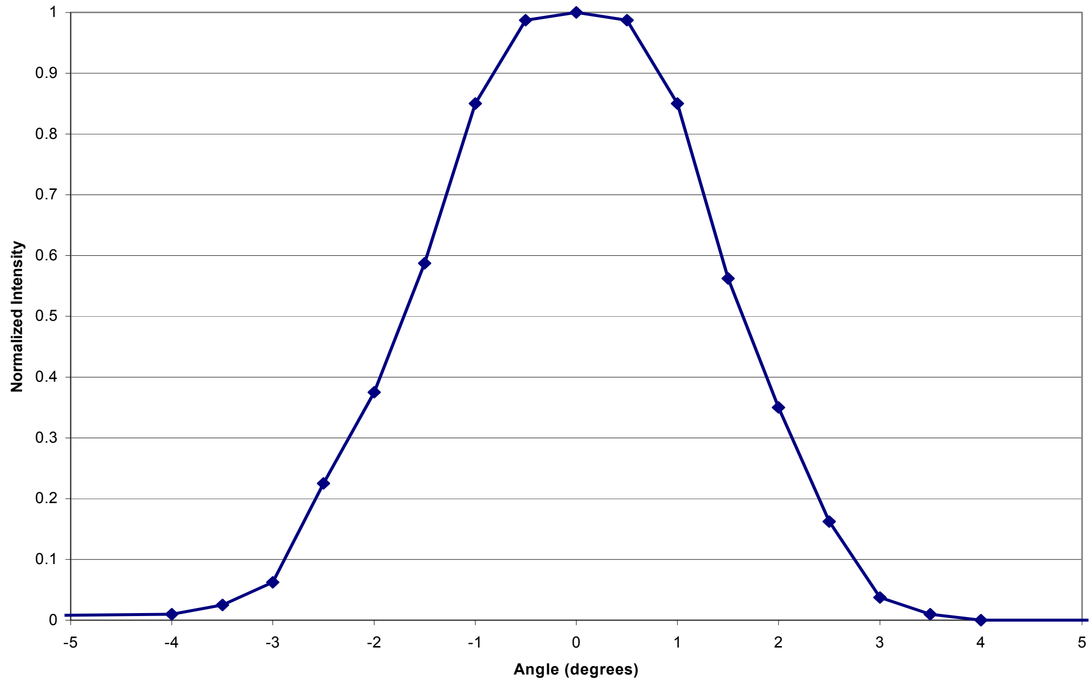

Figure 2. Normalized received intensity of ultrasound beam reflected from a vertical pole vs. angle of pole off central beam axis.

These additional transducers would not be as collimated as the central transmitter, so these additional beam patterns would be on the order of 3 to 4 feet at distances beyond 10 feet. However, since the receiver would still be in a collimated configuration (looking at a spot on the order of 6 inches diameter), there should be little interference from reflections outside the existing FOV. The effect is analogous to viewing an object with a microscope and using additional side lighting for increased illumination.

2.2.2. Dynamic detection threshold

In order to enhance the signal-to-noise (or signal-to-clutter) ratio, for a given set of conditions (range, weapon type, and clothing type), a variable or dynamic detection threshold setting will be implemented. In the present design, the threshold for detection is set for an unarmed person wearing a light cotton shirt standing at a range of about 7 feet. For these conditions, only one light (actually the power ON light) on the 5-light LED display is illuminated. The disadvantage of a fixed threshold setting is that for clothing materials with an above-average reflectivity, the total dynamic range of the detector is not utilized and there is a tendency for the number of false-positive alarms to increase.

A dynamic, or variable, detection threshold setting would enable the user to tailor the sensitivity of the detector according to the type of clothing a suspect is wearing. Operationally, the user would point the detector at several different areas on the suspect (both front and back as the suspect is directed to turn around slowly) and the light bar indicator would show the readings for each area while preserving the dynamic range of the detector. For example, using the present prototype, the number of lights illuminated (out of a total of 5), might be 3, 4, 4, 5 (max), and 3 for five different areas on the suspect. Normally, the reading of 5 would be a strong indicator of a concealed reflecting object. However, since none of the readings were at a minimum, i.e., 1, the dynamic range of the detector is underutilized and the highest reading may simply be an above average reflectance from clothing. An active or dynamic threshold for detection would sense the average level of reflectance and automatically adjust the low end of the detector to compensate for clothing materials with an above average reflectance. Thus, if the individual had been armed, with the weapon located in the area that gave the maximum reading, the readings would have been 1, 2, 2, 5 (max) and 1 for the same five areas. The reading of 5 would now be a much stronger, i.e., higher probability, indicator of the presence of a weapon. Thus, the variable threshold circuit would basically adjust the zero-level of reflectance in order to preserve the dynamic range of the detector. The net effect would be an increased probability of detection. This function will be implemented as part of the analog processing electronics in the present prototype.

2.2.3. Use of multiple and/or different frequencies

Another approach towards increasing the probability of detection will be to utilize a different frequency, or more than one frequency, of ultrasound energy. Higher frequencies are able to resolve an object's spatial location more precisely, whereas lower frequencies are able to better penetrate through clothing. For example, a configuration using two transducers with one operating at 40 kHz and the other at 20 kHz might provide for increased detectability by allowing the 20-kHz energy to better penetrate and detect an object (although with diminished spatial resolution). Using the same collimating optics as in the present prototype, the spatial resolution at 20 kHz would be on the order of 1 foot at range of 10-12 feet. Operationally, given an indication of a concealed object somewhere on the suspect's person from the 20-kHz transducer, the 40-kHz transducer would then be used to indicate more precisely where on the suspect the object might be. This strategy should work best in conjunction with a dynamic detection threshold capability as discussed in Sec. 2.2.2 since the higher frequency transducer (40 kHz) is likely to have an above-average reflectance relative to the lower frequency source. The disadvantage of using two separate frequencies is that it would likely require a more complicated optical configuration since the two sources would need to be coaxial or have different collimating optics.

2.2.4. Signal-Shape Discrimination

A fourth upgrade to be considered is one involving data processing of the return (reflected) signal. During previous efforts, it has been noted that the return pulse is often characterized by a unique waveform or shape of the pulse envelope that is dependent upon the shape of the object being detected. With the existing CWD-2000 units, motion of the handheld unit over a target spot also results in temporal changes to return signals, particularly if a hard, reflecting object is present in the target region. To date, we have only noted this result; however, we believe that we can reduce this observation to practice. Signal-shape discrimination would involve an analog differencing and comparator circuit to determine the extent of the signal transients. It remains to be determined whether alarm thresholds would be modified based on difference signals alone or a combination of difference signals and comparison to a library of waveforms for different shapes and object types, e.g., cylinders, flat plates, spheres, etc.

To pursue this concept, a series of laboratory measurements will be made to quantify sensor signals, recording amplitude as a function of time and motion of the sensor and object type. Using signal processing algorithms developed under an IR&D effort [Ref.], these data will then be compiled and analyzed to determine the correlation matrix for each type of concealed object. Once this so-called neural net has "learned" a set of conditions that correctly identifies all concealed objects in laboratory test conditions, the algorithms will be tested against additional new data. The results will be scored in terms of the number of false positives and false negatives in addition to percent accuracy. Following a review of these results, the processing algorithms will be analyzed to determine the most cost-effective rendering in electronics and then be implemented between the analog and digital sections in the sensor.

3. TECHNICAL PROGRAM SUMMARY

There are three main technical challenges associated with the present development effort that we feel are of primary concern as follows:

1. Ability to distinguish hard objects under thick or reflective clothing.
2. Ability to resolve hard objects at maximum desired range, i.e., 30 feet.
3. Acceptable false alarm rate.

With regards to object detection through reflective clothing, we are pursuing a two-pronged approach consisting of a dynamic detection threshold feature and multiple frequencies to increase the probability of detection through thick or reflective clothing. The dynamic detection threshold will allow for more useable sensitivity when viewing a person wearing clothing with a high ultrasound absorptance or reflectance. A lower frequency transducer, while having a larger spot-size, will be more penetrating and may provide additional information for the signal processing to allow detection. However, there will likely still be certain clothing types that will be very difficult to "see" through. For example it is unlikely that ultrasound will be capable of penetrating a stiff plastic or vinyl raincoat. This is an inherent limitation associated with

ultrasound and the acoustic impedance mismatch between a hard surface and air. Table 1 shows the measured attenuation through various clothing types as measured at 40 kHz. Note that these numbers are then squared when calculating round-trip transmission.

Clothing Material Type	% Transmission (Amplitude)
Heavy Polyester Sweatshirt	69
Nylon/polyester shop coat	67
Cotton flannel shirt	57
Acrylic sweatshirt	52
Wool sweater	47
Woolen Navy pea coat	34
Cotton sweatshirt	23
Woolen suits	12-18
Down-filled coat w/nylon shell	1.4

Table 1. Amplitude of ultrasound signal transmitted through various articles of clothing at 40 kHz as a percentage of baseline signal measured at the same 2-meter distance with no intervening clothing.

For detection at increased range, we will employ multiple transducers to allow for more uniform illumination of the subject and an increased range of glint angles. This will increase the probability of being able to see a reflected signal, as discussed in Section 2.1.1. The risk associated with this approach is relatively low, since the increased circuitry needed to drive an additional one or two transducers is minimal. We have also previously demonstrated that by using two transducers at different illumination angles, the received signal increases.

Note that, although ultrasound is attenuated with range, the present limitations on range are due to the limited angles of incidence presented to the target by the highly collimated ultrasound beam. Ultrasound at 40 kHz is absorbed and scattered in air at a rate of about 1.3 dB/m, depending on humidity [Ref. 4]. At the maximum range goal of 30 feet (about 10 meters), this corresponds to a roundtrip absorption loss of 26 dB. In addition to this non-negligible absorption by air, the signal voltage amplitude decreases roughly as $1/r^2$ for a diffuse scatterer. This was measured in a previous effort [Ref.] and the data is shown here in Fig. 3. This differs from the decay of the ultrasound signal when reflected from a large planar surface, such as a wall, which falls off as 1/r. (The signal intensity would decay as the voltage squared, or as the –2 and –4 powers of range, for a purely specular reflector and a diffuse scatterer, respectively.)

Compensating for the decay of the received signal voltage with range is an essential feature of the ultrasound detector. Without compensation, the false alarm rate would be unacceptably high at close range and the probability for detection, P_D, would be unacceptably low at more distant ranges. The compensation in the prototype was accomplished by using a wideband, variable-gain amplifier IC as part of the analog signal detection circuitry. Since the signal reflected from a cylindrical pole scaled the same as that of a concealed handgun, we use the pole as a convenient target in adjusting the circuit parameters to flatten the voltage response as a function of range.

Increasing the probability of detection may also lead to an increase in the false alarm rate. We are planning on using signal shape discrimination to overcome this potential problem. That is, by sensing the characteristics of the return waveform envelope, we hope to discriminate against signals from reflective clothing (which look essentially the same as the transmitted signal) and signals due to reflections from hard objects. A series of measurements will be made to characterize the return envelopes from a variety of basic shapes (disc, cylinder, and sphere). The data from these measurements will be compared to the waveforms from reflection data using planar surfaces and the waveform differences quantified. These differences will then be used in conjunction with a field programmable gate array (FPGA) circuit to allow the detector to discriminate between the two types of reflections.

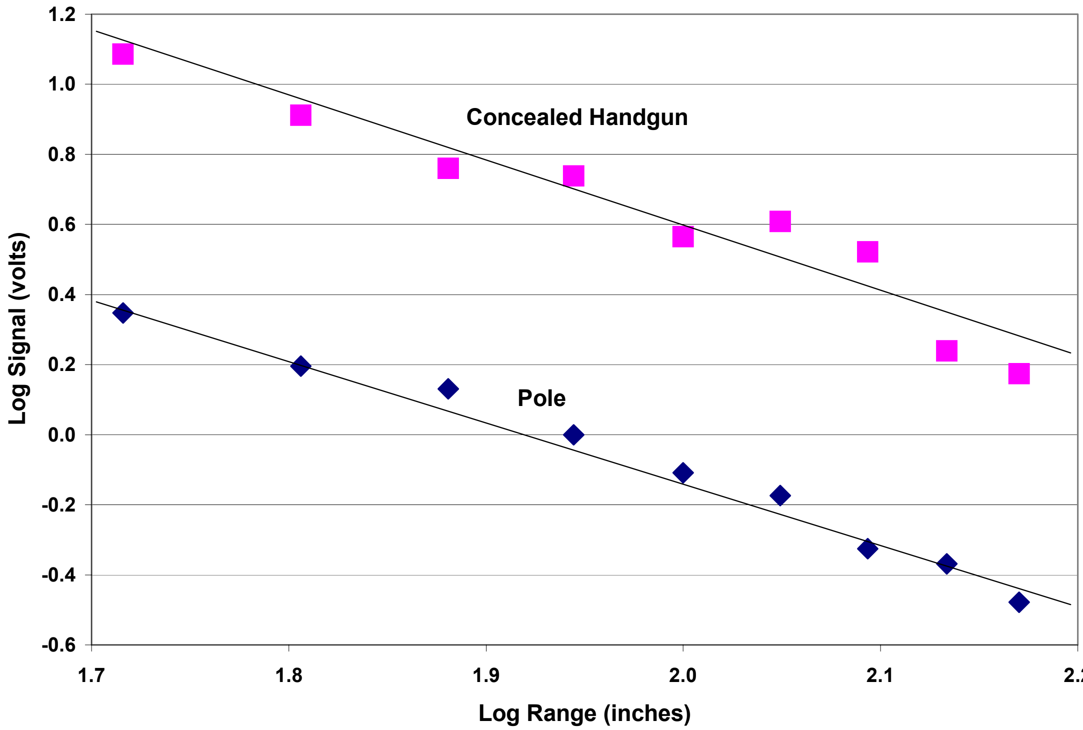

Figure 3. Signal voltage (log volts) vs. range (log inches) measured for ultrasound signal reflected from a ½" pole and from a concealed handgun (under sweater) on body at same gain setting. Straightlines have slope of –1.9.

4. CONCLUSIONS

The main objective of the current CWD program is to put improved CWD prototypes into the hands of local law enforcement. The 20-month program will produce 20 second-generation prototypes for evaluation and field use by law enforcement personnel. The principal goal is to develop a product that will eventually be demanded by law enforcement officers for their own protection, protection against weapon attacks and against liability, and to enhance their own effectiveness. The need for concealed-weapons detection by community law enforcement already exists. Our aim is to provide an effective solution in a low-cost, handheld package that will come to be considered by officers to be as indispensable as body armor.

ACKNOWLEDGEMENTS

This work was supported by the Air Force Research Laboratory at Rome, N.Y. under Contract F30602-00-C-0204.

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APPENDIX B: HANDHELD ULTRASONIC CONCEALED WEAPON DETECTOR

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ABSTRACT

A handheld, battery-operated prototype of a concealed weapon detector (CWD) has been built and tested. Designed to detect both metallic and non-metallic weapons, the sensor utilizes focussed ultrasound (40 kHz frequency) to remotely detect concealed objects from beyond arm's length out to a range of about 25 feet (8 meters). Applications include weapon detection in prison settings, by officers in the field for stand-off frisking of suspects, and as supplemental security at courthouse entrances and other monitored portals. The detector emits an adjustable, audible alarm (with provision for an earphone jack) as well as a visible light-bar indicator when an object has been detected. An aiming light, with momentary switch, allows the user to accurately determine the location of the concealed object. A presentation of the detector's capabilities and limitations will be presented along with probability of detection (P_D) data obtained using the latest prototype version.

Keywords: Ultrasound, concealed weapon, detector, handheld, nonmetallic

1. INTRODUCTION

This paper describes an ongoing effort to develop a handheld device for detection of both metallic and non-metallic concealed weapons using ultrasonic technology. Jaycor is currently developing, under government sponsorship, a hand-held ultrasonic device capable of concealed weapon detection for use by law enforcement and security personnel. Under contract to the National Institute of Justice (NIJ), 20 second-generation units are being fabricated for delivery and evaluation to the Air Force Research Laboratory in Rome, NY. The second-generation units are based on the technology developed under a previous effort that resulted in the production of several prototype handheld units that were shown to be effective at detecting both metallic and non-metallic concealed weapons at distances up to 12 feet[1,2].

As a result of that successful prototype development program, a follow-on effort for enhancing the detector's ability to see through a wider range of clothing material types was initiated. The initial prototype detector was somewhat limited as to its ability to "see" through heavy clothing such as leather jackets and winter parkas which have a relatively high reflectance for the ultrasound waves emitted by the device. The second generation units have been modified with higher output power transducers and more sensitive detection circuitry to enable better clothing penetration while at the same time allowing for an extended range of detection out to 25 feet. Due to the inherently high reflectivity of ultrasound energy from leather and other heavy or tightly knit synthetic materials, the device is most effective when viewing objects under woven materials such as sweatshirts, sweaters, wool suit coats and the like.

Applications of this concealed weapon detector (CWD) include remote pat-downs by law enforcement (LE) officers before moving in to do a hands-on search that would still be required. As such, the detector could provide "probable cause" for performing a more intensive search of a suspect. In addition, simply pointing the detector at a suspect can elicit behavioral changes that an experienced officer could observe.

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It is important to note that this detector can not tell the difference between a weapon and an ordinary object such as a cell phone, a bunch of keys, credit cards etc. which can all trigger false alarms. However, our philosophy has been that a false alarm from a harmless item is preferable to not being able to detect a potentially dangerous weapon. Under the current effort, we have improved the signal processing of the device to lower the false-alarm rate and also increased the probability of weapon detection through heavy clothing.

Product availability will depend to a large degree on the outcome of this upgrade effort and subsequent evaluation by the government. We presently see these devices becoming commercially available in the early 2003 time frame with a projected price of less than $500. The ultimate goal is an affordable, hand-held, standoff weapon detection device.

2. CONCEALED WEAPON DETECTOR CONCEPT

The hand-held detector is an outgrowth of a more complex sensor design that was capable of imaging concealed weapons. The first-generation prototypes of the hand-held unit, dubbed the CWD-2000, were designed to simply detect (yes/no), rather than image, concealed weapons up to a range of about 12 feet. The detector operates in much the same way as a commercial range finder, but at higher peak acoustic intensities and higher repetition rates. The detector alerts the user to the presence of a concealed object using an audible tone and a visible light-bar indicator. On-board receiver electronics monitor ultrasound glints above a body/clothing background level while compensating for changing range and attenuation. A photograph of one of the first generation CWD-2000 prototype units is shown in Figure 1.

Figure 1. Photograph of one of the first generation CWD-2000 prototype handheld units.

2.1. CWD Features and Technical Specifications

The prototype CWD-2000 has a number of operating features that have been carried over into the second-generation (CWD-2002) units. Both units utilize a single 40-kHz ultrasonic transceiver. The CWD-2000 can detect concealed weapons (either metallic or nonmetallic) at distances up to 12 feet away through a limited set of clothing material types on a stationary individual. The ultrasonic beam pattern of the detector is a circular spot about 7 to 12 inches in diameter at ranges from about 3 to 12 feet. The CWD-2000 units work reasonably well at finding objects between 3 to 12 feet in front of the detector, with the highest probability of detection from 4 to 7 feet. It does not work at all closer than about 3 feet due to a range-gating feature that isolates the sensitive receiver electronics from the large transmit pulse. This feature has also been carried over into the CWD-2002 units. With a modified transmit drive circuitry and increased sensitivity on the receive electronics, the CWD-2002 units can detect concealed objects out to 25 feet.

In operation, the detector should be aimed first at areas of clothing where weapons are likely to be concealed, including, of course, any obvious bulges in clothing. Once pointed at an area, the detector is then moved from side to side and up and down, using the aiming light to keep the detector pointed at the spot of interest. The side to side and up and down motion of the detector allows it to view the spot from a wider range of angles, increasing the probability of detection.

As the user inspects the suspect, when an alarm sounds, the user should then return to the area that produced the alarm and concentrate a search there to determine the view angle that gives the strongest alarm. Level 4 or 5 alarms (as shown on the LED light bar) are strong indications of a concealed object. For precise aiming, a focussed 5-W halogen lamp allows the user to determine where on a person the detector is pointed. As a side benefit for law enforcement, the high-intensity light can also be used as a spotlight or to temporarily disorient a suspect. We have incorporated a low power laser pointer as an aiming light into the CWD-2002 units to allow for more covert operation. This feature also allows for operation off a single battery pack which reduces the weight of the handheld unit. In the CWD-2000 units, the detector and aiming light circuitry are powered by separate battery packs.

An audible alarm, normally heard through the rear-mounted speaker, can be optionally heard using an earphone jack that mutes the speaker when in use. An adjustable knob on the back of the detector controls the loudness of the speaker and earphone. The tone is designed to increase in pitch and intensity as a function of increasing received signal level. A visible alarm indicator in the form of a 5-level light bar on the back of the detector housing shows the relative intensity of the received signal. The lowest level is used as a power ON indicator (with trigger pressed). The detector is designed to look for concealed weapons as long as the trigger is pressed. All of these alarm features have been carried over into the CWD-2002 units.

2.2. Second-Generation Upgrade Activities

There were four upgrade activities pursued for the second-generation units under the current effort. The results of these activities have been assessed and incorporated, where feasible, into the upgraded design. At the end of the current effort, 20 functional CWD-2002 units will have been fabricated, tested and delivered to AFRL for further field-testing and evaluation. A brief description of the four upgrade activities and the results of each follow.

2.2.1. Multiple transducers

With both the initial CWD-2000 design and the CWD-2002, the user must move the detector from side to side and up and down while focussing on a fixed spot to maximize the viewing angle of the detector and thus increase the probability of detection. This is a result of the relatively narrow field of view (FOV) of the detector/antenna configuration (3-5 degrees). The narrow FOV is necessary to have a spatial resolution on the order of 6 inches (a typical handgun or knife dimension) at a range of 12 feet. If the reflected acoustic energy is not within the FOV, the detector can be pointed at a concealed item and not "see" it. Fortunately, most weapons, like handguns, have multiple facets that generate their own specular reflection.

A 5-inch diameter parabolic dish is used to collimate the diverging ultrasound beam source. The effective full-width-at-half maximum (FWHM) transmitted intensity was measured to be 3.0 degrees as shown in Figure 2. This divergence, while small, corresponds to an effective field of view of about 7" on a target at 12 feet range. Thus, the small divergence gives an acceptable spot size at the desired range but also limits the sensitivity of the detector to off-axis glint angles. At the extended range of 25 feet, the lateral extent of the FOV for the CWD-2002 is about 17 inches.

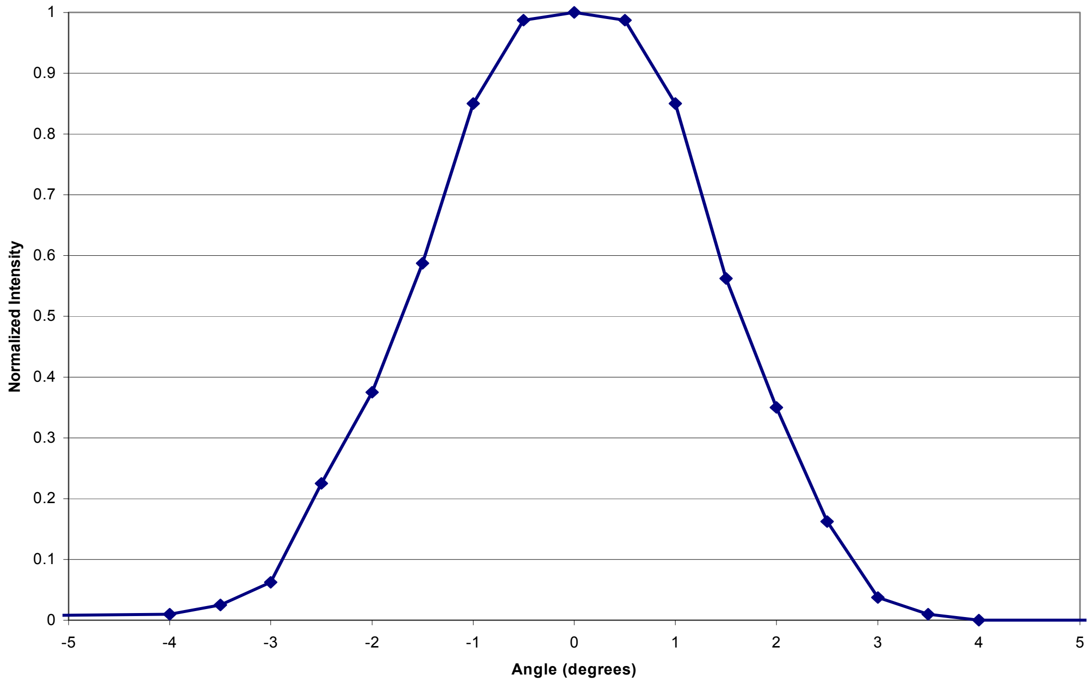

Figure 2. Normalized received intensity of ultrasound beam reflected from a vertical pole vs. angle of pole off central beam axis.

This glint angle sensitivity affects the probability of detection, P_D, because of the chance that the detector will not irradiate a facet of the weapon at near normal incidence (within the FOV of the detector). Since most concealed weapons, like handguns or knives, are carried flat against the body, the best angle for aiming the detector at each spot, therefore, is normal to the body surface. Presently, the most effective way to use the detector is to aim it at locations on the body where weapons are likely to be concealed, and then use lateral and vertical motions of the arm to cover a range of angles about the normal while aiming at the same spot.

Since the range of angles of incidence of the ultrasound beam on a suspect is limited, it becomes harder to detect objects with increasing range. To alleviate this problem, i.e., to increase the probability of detection, the use of additional transducers was thought to have the potential for effectively increasing the FOV of the detector while maintaining the desired spatial resolution. We installed additional ultrasound transmitters around the periphery of the existing cylindrical shield cage using two and then four separate transmitters to determine if this approach would be effective. To increase the effective viewing angle even further, a folding support arm for each transducer was also examined. For example, using a 4-inch radial extension arm for each transducer would theoretically increase the viewing angle from the current 3 degrees to about 9 degrees.

These additional transducers were not collimated (only the central transmitter was collimated), so their beam patterns were on the order of 3 to 4 feet in lateral extent at distances beyond 10 feet. However, since the receiver was still in a collimated configuration, i.e., looking at a spot on the order of 6 inches diameter, there was little observed interference from reflections outside the existing FOV. The effect is analogous to viewing an object with a microscope and using additional side lighting for increased illumination. There were two problems encountered with these configurations that eventually determined that the addition of extra transmitters was not useful in increasing P_D. First, due to the large divergence of the peripheral transmitters, the power on target (within the field of view) was relatively small when compared to the power being delivered by the collimated co-axial source. Thus, the central collimated source tended to dominate any reflected signal, minimizing the advantage of the additional illumination. Without using rather large and cumbersome collimators on these peripheral transmitters, this approach did not yield any significant increase in the effective field of view. Secondly, there was a problem with constructive and destructive interference between the different transmitters that resulted in erroneous readings when viewing an object at slightly different angles.

2.2.2. Dynamic detection threshold

In order to enhance the signal-to-noise (or signal-to-clutter) ratio, for a given set of conditions (range, weapon type, and clothing type), a variable or dynamic detection threshold setting is being considered. In the present design, the threshold for detection is “factory set” for an unarmed person wearing a light cotton shirt standing at a range of about 7 feet. For these conditions, only one light (that also serves as the power ON light) on the 5-light LED display is illuminated. The disadvantage of a fixed threshold setting is that for clothing materials with an above-average reflectivity, the total dynamic range of the detector is not utilized and there is a tendency for the number of false-positive alarms to increase.

A dynamic, or variable, detection threshold setting will allow the sensor to adjust its sensitivity according to the type of clothing a suspect is wearing. Operationally, the user would point the detector at several different areas on the suspect (both front and back as the suspect is directed to turn around slowly) and the light bar indicator would show the readings for each area while preserving the dynamic range of the detector. The circuitry for an active or dynamic threshold for detection is being designed to sense the average level of reflectance and automatically adjust the low end of the detector to compensate for clothing materials with an above average reflectance. Thus, the dynamic threshold circuit adjusts the zero-level of reflectance in order to preserve the dynamic range of the detector. The net effect will be an increased probability of detection. This function will be implemented as part of the analog processing electronics in the CWD-2002 units.

2.2.3. Use of multiple and/or different frequencies

The use of ultrasonic frequencies other than 40 kHz was also examined under the current effort. Higher frequencies are able to resolve an object’s spatial location more precisely, whereas lower frequencies are able to better penetrate through clothing more readily. A 60 kHz transducer was examined but found to have too high attenuation (about 2.3 dB/m) in air and not enough initial drive power to be useful. A configuration using two transducers with one operating at 40 kHz and the other at 23 kHz was also examined in the hope that increased detectability could be achieved by allowing the 20-kHz energy to better penetrate and detect an object (although with diminished spatial resolution). Using the same collimating optics as in the CWD-2000, the spatial resolution at 23 kHz was found to be on the order of 10 inches at a range of 10-12 feet. The disadvantage of using two separate frequencies is that it requires a more complicated focussing/collimating configuration since the two sources need to be coaxial or have different, and bulkier, collimating optics. Also, the 23 kHz transducers were much bigger than the 40 kHz elements and did not seem to provide for any significant increase in P_D.

2.2.5. Signal-Shape Discrimination

A fourth approach that was considered involved data processing of the return (reflected) signal. During previous efforts, it had been noted that the return pulse is sometimes characterized by a waveform that is dependent upon the shape of the object being detected. With the existing CWD-2000 units, motion of the handheld unit over a target spot also results in temporal changes to return signals, particularly if a hard, reflecting object is present in the target region. After a series of measurements on a variety of two-dimensional targets of different shapes (square, circle, elongated rectangle, etc.) no consistently discernible differences in waveform signature relative to target shape were observed.

3. TECHNICAL PROGRAM SUMMARY

There were three technical challenges associated with the present development effort that we identified as being of primary concern as follows:

1. Ability to distinguish hard objects under thick or reflective clothing.
2. Ability to resolve hard objects at maximum desired range.
3. Acceptable false alarm rate.

With regards to object detection through reflective clothing, we are pursuing a three-pronged approach consisting of a dynamic detection threshold feature, using increased power on the transmitter source, and increasing the sensitivity of the receiver electronics. The dynamic detection threshold will allow for more useable sensitivity when viewing a person wearing clothing with a high ultrasound absorbtance or reflectance. The higher power source allows for increased return signals from concealed objects while the increased detection sensitivity increases P_D. However, there will likely still be certain clothing types that will be very difficult to "see" through. For example it is unlikely that ultrasound will be capable of penetrating a stiff synthetic plastic or vinyl raincoat. This is an inherent limitation associated with ultrasound and the acoustic impedance mismatch between a hard surface and air. The attenuation through various clothing types has been measured and reported earlier[2].

The increased power and detection sensitivity also helps us towards meeting the second challenge of increased range. Note that, although ultrasound is attenuated with range, the present limitations on range are due to the limited angles of incidence presented to the target by the highly collimated ultrasound beam. Ultrasound at 40 kHz is absorbed and scattered in air at a rate of about 1.3 dB/m, depending on humidity[3]. At the maximum range goal of 30 feet (about 10 meters), this corresponds to a roundtrip absorption loss of 26 dB. In addition to this non-negligible absorption by air, the signal voltage amplitude decreases roughly as $1/r^2$ for a diffuse scatterer. This was measured in a previous effort[2]. We have currently been able to detect objects out to a limit of 25 feet (8 meters). Extending this range out to 10 meters would require a larger collimating dish and a higher power source to maintain the field of view, both of which would likely make the unit intractable for handheld use.

The third challenge, an acceptable false alarm rate, is presently the most difficult to meet. It is very difficult for the device to distinguish between a reflecting object and certain highly reflecting cloth types, e.g., leather. This is compounded by the observation mentioned previously that there were no discernible differences in the return signal relative to the object shape. Thus, we feel that the device, while useful in certain applications, e.g., controlled settings such as prisons, LE pat-downs and portal control facilities, the use of the device on the general public in an uncontrolled crowd setting or the like may be limited.

A cut-away drawing of the CWD-2002 design is shown in Figure 3. The single, rechargeable battery pack is contained within the handle grip. Readout displays, audio jack and user controls are located on the back panels. The low-power laser pointer aiming light is contained within the transducer housing and is coaxial with collimated ultrasound beam.

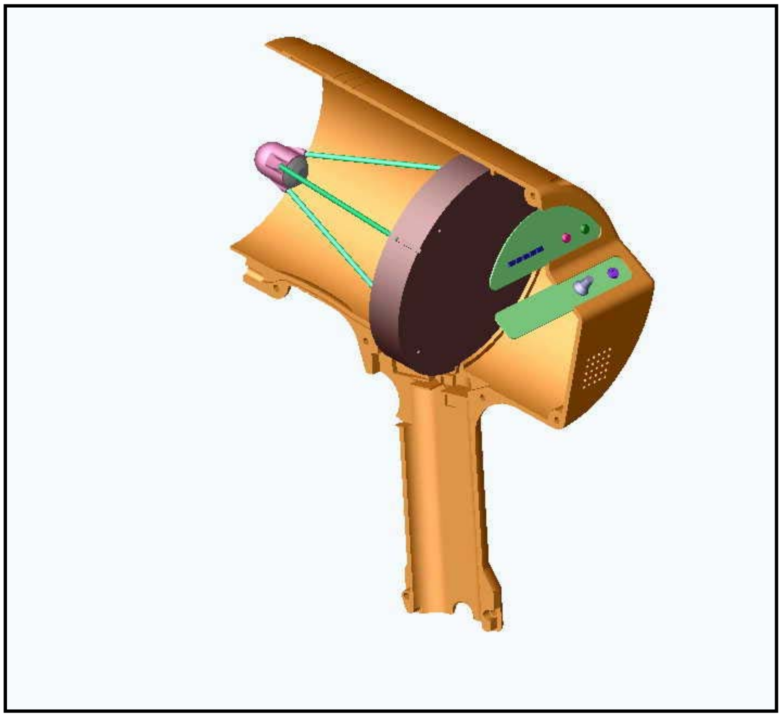

Figure 3. Drawing of the CWD-2002 showing the internal collimating dish, tripod-mounted transducer/aiming light assembly and rear control panels.

4. CONCLUSIONS

The main objective of the current CWD program is to put improved CWD sensors into the hands of local law enforcement. At the end of this effort, 20 second-generation units will be delivered for evaluation and field use. The principal goal is to develop a product that will eventually be demanded by law enforcement officers for their own protection, protection against weapon attacks and against liability, and to enhance their own effectiveness. The need for concealed-weapons detection by community law enforcement already exists. Our aim is to provide an effective solution in a low-cost, handheld package that will come to be considered by officers to be as indispensable as body armor.

ACKNOWLEDGEMENTS

This work was supported by the Air Force Research Laboratory at Rome, N.Y. under Contract F30602-00-C-0204.

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APPENDIX C

HANDHELD CONCEALED WEAPONS DETECTOR DEVELOPMENT

- Program Review -

August 6-7, 2002

Ft. Belvoir, VA

JAYCOR POC: Dr. Norbert Wild
(858)-720-4085, nwild@titan.com

CONCEALED WEAPONS DETECTOR DEVELOPMENT

PROGRAM OVERVIEW

- Rome Lab / NIJ - sponsored effort (8/00-8/02)
- Follow-on to program which developed first handheld ultrasonic weapons detector
- Emphasis on improving Jaycor CWD prototype
  - Reduce false-alarm rate
  - Decrease angular sensitivity
  - Enhance clothing penetration
  - Increase effective range
- Produce quantity of 2nd-generation prototypes for field use and evaluation

CONCEALED WEAPONS DETECTOR DEVELOPMENT

PROGRAM OBJECTIVES

- Develop an enhanced, handheld, low-cost (< $1,000) ultrasonic CWD
  - Increase range from 12 ft to 30 ft
  - Reduce false positive alarm rate
  - Decrease pointing angle sensitivity from ± 5 degrees to ± 45 degrees.
- Build a number (≈ 20) of working models for further government test and evaluation

CONCEALED WEAPONS DETECTOR DEVELOPMENT

PREVIOUS PROTOTYPE
CWD-2000

CONCEALED WEAPONS DETECTOR DEVELOPMENT

PREVIOUS CWD-2000 SPECIFICATIONS

- Handheld ultrasonic (40 kHz) detector locates hard objects (metal, glass, plastic) under various clothing types
- Effective Range: 4-12 ft.
- Trigger activated with separate aiming light switch
- 5-level visual LED detection indicator
- Variable pitch audible alarm with earphone plug
- Batteries: Rechargeable NiCad
  - Detector - 15 hour continuous operation
  - High Intensity Aiming Light - 1 hour continuous
- Weight: 2 lb 15 oz (including batteries)

CONCEALED WEAPONS DETECTOR DEVELOPMENT

2nd GENERATION MODEL CWD-2002

CONCEALED WEAPONS DETECTOR DEVELOPMENT

2nd GENERATION CWD-2002 SPECIFICATIONS

- Handheld ultrasonic (40 kHz) detector locates hard objects (metal, glass, plastic) under various clothing types
- Effective Range: 4-25 ft.
- Trigger activated with separate aiming light switch
- 5-level color-coded LED detection indicator
- Variable pitch audible alarm with earphone plug
- Batteries: Rechargeable NiCad porta-pak
  - Detector - 8 hours continuous operation
  - High Intensity Aiming Light - 1 hour continuous
  - Laser Diode Aiming Light Option - 8 hours continuous
- Weight: 3 lb (including batteries)

CONCEALED WEAPONS DETECTOR DEVELOPMENT

Model CWD-2002 Aiming Lights

Collimated Quartz Halogen

Red Laser Diode

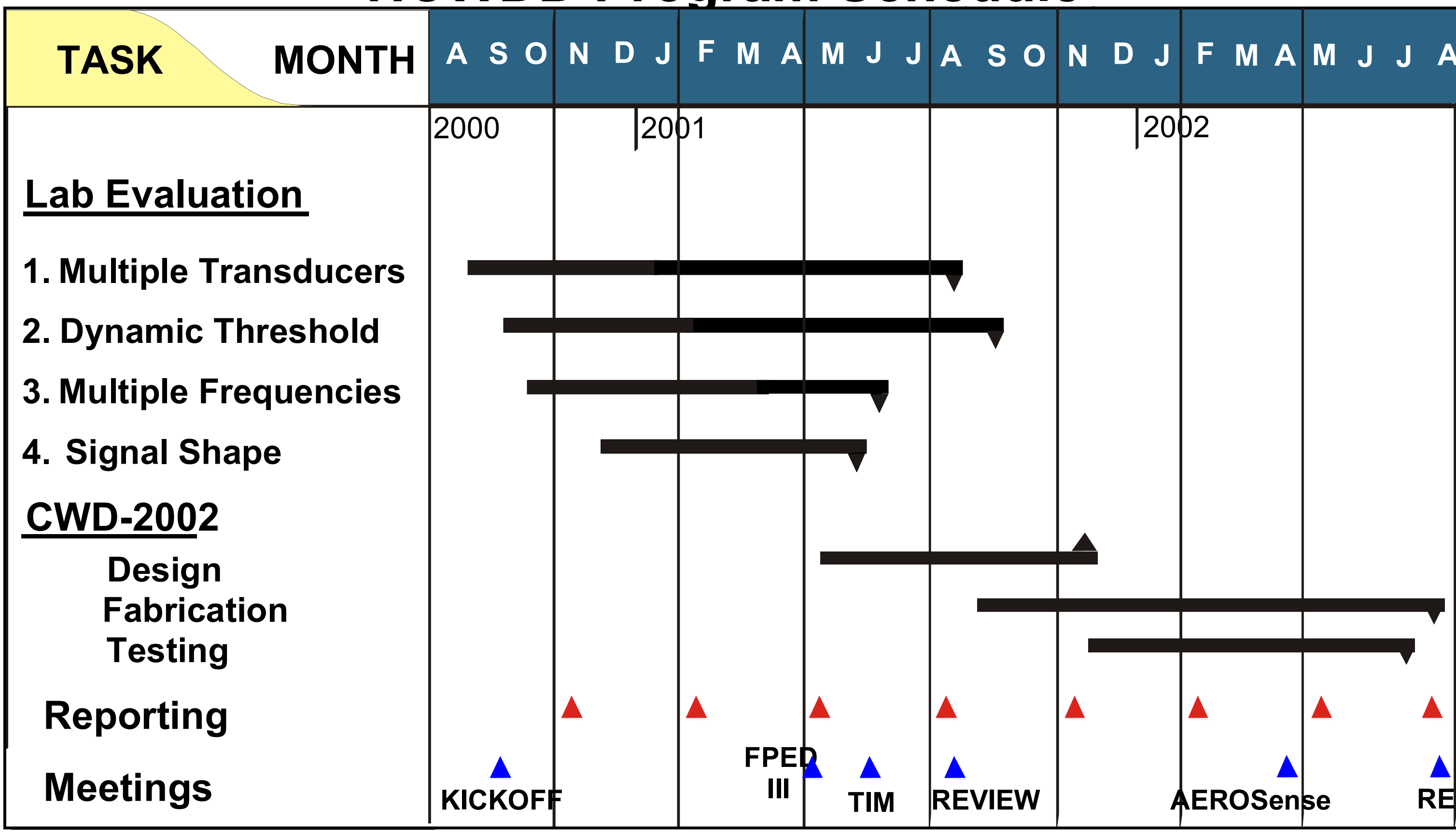
CONCEALED WEAPONS DETECTOR DEVELOPMENT

PROGRAM TASKS

- Quantify performance of previous prototype (CWD-2000) for variety of clothing types
  - Range, P_D, angle-of-view, false alarm rate
- Test and evaluate proposed design modifications relative to existing performance parameters
  - Multiple transducers
  - Dynamic thresholding
  - Multiple frequencies
  - Signal shape discrimination
- Incorporate results into brassboard CWD prototype
- Evaluate and quantify brassboard CWD performance
- Fabricate 20 CWD-2002 prototype units for field testing

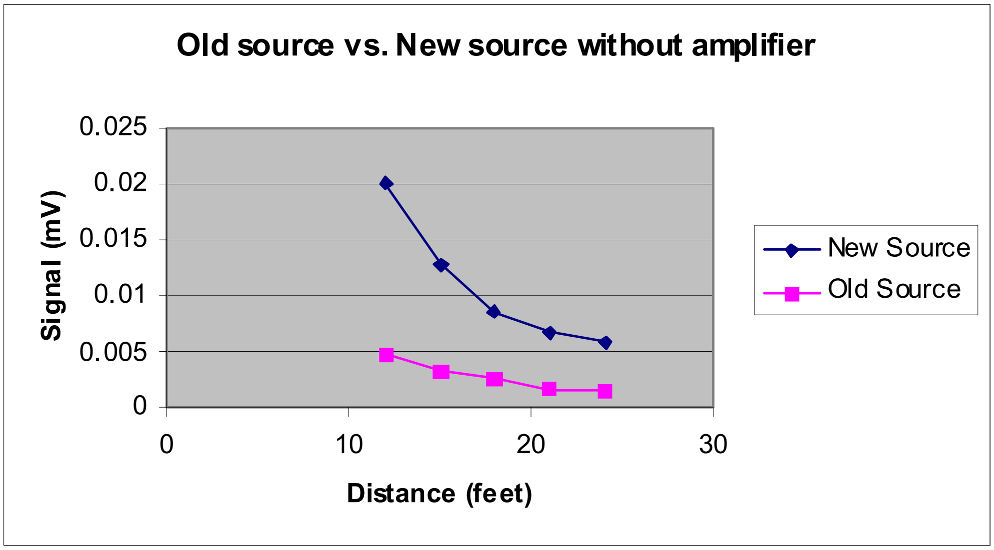
CONCEALED WEAPONS DETECTOR DEVELOPMENT

HCWDD Program Schedule



Extended Range Test Data

- Higher power drive developed -- 4X old power
- No increase in size or weight for more output power
- Solid cylindrical housing (no perforations) helps maintain signal to noise ratio at max range



CONCEALED WEAPONS DETECTOR DEVELOPMENT

MULTIPLE TRANSDUCERS

- Previous CWD-2000 used single, collimated (< 2 degrees) transducer for transmit and echo receive functions
  - Narrow beam needed for 6” spatial resolution and object location
- Beam spread on uncollimated transducer is ± 15 degrees
- Use of additional off-axis, uncollimated transducers acting as diffuse illuminators of target yields more reflected energy entering FOV
- However, beyond 10-12 feet, central source dominates minimizing any advantage of off-axis illumination
- Destructive interference between off-axis sources also gave rise to erroneous readings at wide viewing angles

ADDITIONAL PROTOTYPE MODIFICATIONS

- Changed out existing speaker to piezoceramic type for louder alarm indication (when not using earphone)
- Parabolic reflector made with lightweight plastic resin material
- Single battery pack for electronics to minimize parts count
- Center of gravity lowered by placing battery pack in hand-grip
- Battery charge-level indicator added
- Removeable battery pack enables re-charge of spare battery pack during use
- Light-bar indicator changed to multi-color LEDs (green/yellow/red)

CONCEALED WEAPONS DETECTOR DEVELOPMENT

Assessment of Probability of Detection for Previous System

- **Return signal amplitude recorded for:**
  - 3 different targets (cell phone, Beretta 9-mm, pocket knife)
  - 3 different clothing types (none, cotton flannel, synthetic polyester)
  - 3 different target locations (front, side, back - all front illuminated)

No Cloth 6ft away			
	Cell phone	Beretta	Pocket knife
Front	5	5	3
Side	2	3	3
Back	2	2	2
Flannel Shirt			
Front	4	5	3
Side	2	3	1
Back	2	1	1
Shop coat			
Front	3	4	2
Side	2	4	2
Back	2	2	2

No Cloth 12ft away			
	Cell phone	Beretta	Pocket knife
Front	3	4	1
Side	2	2	1
Back	1	1	1
Flannel Shirt			
Front	3	2	2
Side	2	2	1
Back	1	1	1
Shop coat			
Front	3	4	2
Side	2	3	2
Back	2	2	2

No Cloth 18ft away			
	Cell phone	Beretta	Pocket knife
Front	1	2	1
Side	1	1	1
Back	1	1	1
Flannel Shirt			
Front	1	1	1
Side	1	1	1
Back	1	1	1
Shop coat			
Front	3	2	2
Side	2	2	2
Back	2	2	2

- **False negative (level 1) for frontal target 6 out of 27 (22%) out to 18 ft.**
- **False positive (level 4/5) rate likely higher due to clothing reflectance**

CONCEALED WEAPONS DETECTOR DEVELOPMENT

Assessment of Probability of Detection for Present System

- **Return signal amplitude recorded for:**
  - **3 different targets (cell phone, Beretta 9-mm, plastic knife)**
  - **3 different clothing types (none, cotton flannel, synthetic polyester)**

No Cloth 6ft away	Cell phone	Beretta	Knife
Front	5	5	5
Side	2	3	3
Back	2	2	2
Flannel Shirt			
Front	5	5	5
Side	2	2	1
Back	1	1	1
Shop coat			
Front	5	5	5
Side	2	2	2
Back	2	2	2

No Cloth 12ft away	Cell phone	Beretta	Knife
Front	5	5	5
Side	2	2	1
Back	2	2	2
Flannel Shirt			
Front	4	5	5
Side	2	2	1
Back	1	1	1
Shop coat			
Front	4	5	5
Side	2	2	2
Back	2	2	2

No Cloth 25 ft away	Cell phone	Beretta	Knife
Front	4	5	4
Side	1	1	1
Back	2	2	2
Flannel Shirt			
Front	3	5	4
Side	1	2	1
Back	1	1	1
Shop coat			
Front	3	5	4
Side	2	2	2
Back	2	2	2

- **False negative (level 1-3) for frontal target 1 out of 27 (3.7%) out to 25 ft.**
- **False positive (level 4/5) rate still an issue with regards to clothing type**

Progress Report #1 15 November, 2000

APPENDIX D

HANDHELD CONCEALED WEAPONS DETECTOR DEVELOPMENT

F30602-00-C-0204

Jaycor 3148

Reporting Period: 31 July to 31 October, 2000

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 31 July, 2000 (the contract start date) to 31 October, 2000. A brief summary of tasks accomplished and progress made is presented, followed by a synopsis of future plans and goals.

Management/Schedule: We are currently in the third month of the effort with about 7 % of the total program budget having been expended. We anticipate being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: An internal kick-off meeting was held 4 September, 2000 at Jaycor. In attendance were Dr. Norbert Wild, Mr. Dennis Breuner, Mr. Frank Doft and Dr. Peter Coakley. A kick-off meeting with Mr. Ferris from AFRL is planned for the month of November.

A presentation will be made at the SPIE Conference on 7 November in Boston, MA regarding the concealed weapon detection (CWD) technology being developed under this effort. A paper entitled "Handheld ultrasonic concealed weapon detector" was written that will be included as part of the conference proceedings and is attached here as Appendix A.

Laboratory Tests: A test bed for characterizing the performance of the handheld prototype unit has been established in Jaycor's RF/acoustics laboratory in San Diego. In addition to enabling quantification of the false alarm rate, probability of detection, etc., this test bed will allow us to measure changes in performance parameters as a function of each proposed modification to the existing prototype. Shown in Figure 1 is a photograph of the prototype mount that is adjustable in x-y position as well as angular orientation to a distant target. Targets are mounted in front of an anechoic chamber that absorbs extraneous acoustic emissions and alleviates the problem of backscattered ultrasound and multi-path bounces.

Initial tests are being made using a configuration with multiple transducers. As many as four separate transmitters can be mounted circumferentially around the central axis of the prototype unit and transmit pulses in a non-collimated mode coincident with the central collimated transmitter. The central transducer then receives the return echoes from all five transmitters and this signal is acquired for processing. Figure 2 shows a photograph of the multiple transmitter assembly attached to one of the prototype units.

Subsequent tests will be made using various target shapes to acquire data for assessment of the dynamic threshold and signal shape discrimination processing modifications.

Signal Processing: Mr. Dennis Breuner (Jaycor) has begun to examine some of the return waveform signals acquired using various target shapes. This analysis will determine the nature of any signal shape discrimination processing that can be accomplished using analog and/or digital electronics.

Upcoming Activities: A formal kick-off meeting is planned for the month of November with Mr. David Ferris to be held at Jaycor's facility in San Diego, California. Additional testing will be conducted during the months of November and December regarding the signal shape discrimination and multiple transducer upgrade/modifications.

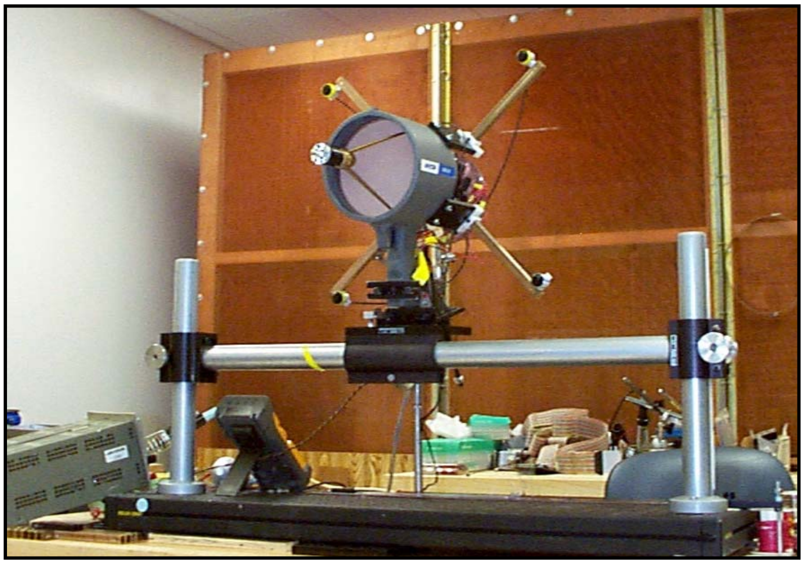


Figure 1. Photograph of CWD adjustable mounting fixture for performance characterization testing.

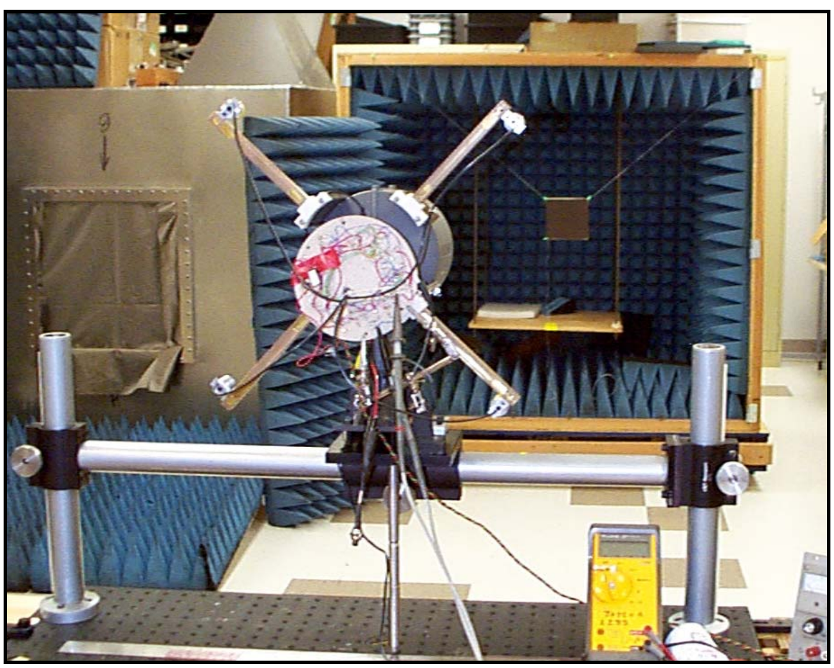


Figure 2. Photograph of CWD adjustable mounting fixture showing downrange anechoic chamber and target area.

Progress Report #2 **15 January, 2001**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 November to 31 December, 2000

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 November, 2000 to 31 December, 2000. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Management/Schedule: We are currently in the fifth month of the effort with about 15% of the total program budget having been expended. We anticipate being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: A presentation was made at the SPIE Conference on 7 November in Boston, MA regarding the concealed weapons detection (CWD) technology being developed under this effort. A paper entitled "Handheld ultrasonic concealed weapon detector" was written and submitted for inclusion as part of the conference proceedings. A copy of the paper was attached as an appendix to the previously submitted Progress Report (11/15/2000).

Laboratory Tests: Testing continued using the CWD test bed for characterizing the performance of the handheld prototype unit. A series of tests are being carried out to characterize the performance of a multiple transducer assembly that has been fabricated as part of Task 1. The electronics to drive the transducers are also being modified to handle the higher power requirements for multiple transducers.

The multiple transducer configuration utilizes as many as five separate transmitters mounted circumferentially around the central axis of the prototype unit. Four separate ultrasonic transmit pulses, in a non-collimated mode, are launched coincident with the central collimated transmit pulse. The central transducer then receives the return echoes from all five transmitters and this signal is acquired for processing.

Additional testing is proceeding with regards to acquiring data on various target shapes. These data sets are being examined as part of Tasks 2 (Dynamic Threshold) and Task 4 (Signal-shape Discrimination).

With regards to Task 3 (Multiple/different Frequencies), several different frequency transducer elements have been ordered for characterization and testing. These include piezo-ceramic devices as well as less efficient piezo-film devices that are inherently lower Q and broader frequency bandwidth, i.e., they can be driven at multiple frequencies. We hope to be able to cover a frequency range from 25 kHz up to 90 kHz, although the higher frequencies will suffer from higher attenuation in air.

Signal Processing: Mr. Dennis Breuner (Jaycor) continues to examine the return waveform signals being acquired using various target shapes as part of Task 4. The goal of this analysis is to determine the nature of any signal shape discrimination processing that can be accomplished using analog and/or digital electronics.

Upcoming Activities: A display of Jaycor's CWD technology and current program status is planned for the NIJ FPED (Force Protection Equipment Demonstration) to be held at Quantico Marine Base on May 8-10.

JAYCOR

Progress Report #3 **15 March, 2001**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 January to 28 February, 2001

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 January, 2001 to 28 February, 2001. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Management/Schedule: We are currently in the seventh month of the effort with about 20% of the total program budget having been expended. We anticipate being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: No meetings were held during the reporting period other than internal status and test planning meetings held at Jaycor.

Laboratory Tests: Most of the effort during this reporting period was focussed on characterizing the multi-transducer assembly that was constructed during the previous reporting period (Task 1). The electronics to drive the transducers were also modified to handle the higher power requirements for multiple transducers.

The multiple transducer configuration utilizes four additional transmitters mounted circumferentially around the central axis of the collimated transducer (transmit and receive). Four separate ultrasonic transmit pulses, in a non-collimated mode, are launched coincident with the central collimated transmit pulse. The central transducer then receives the return echoes from all five transmitters and this signal is acquired for processing.

Initial testing has begun with regards to acquiring data on various target shapes. These data sets are being examined as part of Tasks 2 (Dynamic Threshold) and Task 4 (Signal-shape Discrimination).

For Task 3 (Multiple/different Frequencies), we have had difficulty in finding alternative sources that will operate at frequencies other than 40 kHz and are small enough to be suitable for a hand-held unit. The only vendor who has items available appears to be a US company called Massa that manufactures a 23 kHz transducer (in addition to 40 kHz units). These have been ordered and we are awaiting delivery to begin clothing transmittance measurements.

Signal Processing: Mr. Dennis Breuner (Jaycor) continues to examine the return waveform signals being acquired using various target shapes as part of Task 4. There does not appear to be any discernible differences in signal waveform for different object shapes, e.g., circle vs. square. The main waveform differences are due to the physical size of the object, i.e., larger objects generate return waveforms that appear to be more extended in time. This is consistent with previous observations of overlapping return echoes from multiple targets.

Upcoming Activities: A display of Jaycor's CWD technology and current program status is planned for the NIJ FPED (Force Protection Equipment Demonstration) to be held at Quantico Marine Base on May 8-10.

Progress Report #4 **3 September, 2001**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 March to 31 May, 2001

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 March, 2001 to 31 May, 2001. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Management/Schedule: As of 13 September, we are currently entering the fourteenth month of this 20-month effort with about 40% of the total program budget having been expended. We anticipate being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: In addition to internal status and test planning meetings held at Jaycor, Jaycor participated in the Force Protection Equipment Demonstration III (FPED III) held on May 8-10, 2001 at the Quantico Marine Corps Base in Virginia. A small booth was manned during the course of the FPED III gathering and both CWD (Concealed weapons detection) and TWS (Through-the-Wall Surveillance) programs were presented with demonstrations of both the handheld CWD sensor and the TWS sensor hardware.

Laboratory Tests: Most of the effort during this reporting period was focussed on characterizing the multi-transducer assembly that was constructed during the previous reporting period (Task 1). The electronics to drive the transducers were also modified to handle the higher power requirements for multiple transducers.

The multiple transducer configuration utilizes four additional transmitters mounted circumferentially around the central axis of the collimated transducer (transmit and receive). Four separate ultrasonic transmit pulses, in a non-collimated mode, are launched coincident with the central collimated transmit pulse. The central transducer then receives the return echoes from all five transmitters and this signal is acquired for processing.

Initial testing has begun with regards to acquiring data on various target shapes. These data sets are being examined as part of Tasks 2 (Dynamic Threshold) and Task 4 (Signal-shape Discrimination).

For Task 3 (Multiple/different Frequencies), we have had difficulty in finding alternative sources that will operate at frequencies other than 40 kHz and are small enough to be suitable for a hand-held unit. The only vendor who has items available appears to be a US company called Massa that manufactures a 23 kHz transducer (in addition to 40 kHz units). These have been ordered and we are awaiting delivery to begin clothing transmittance measurements.

Signal Processing: Mr. Dennis Breuner (Jaycor) continues to examine the return waveform signals being acquired using various target shapes as part of Task 4. There does not appear to be any discernible differences in signal waveform for different object shapes, e.g., circle vs. square. The main waveform differences are due to the physical size of the object, i.e., larger objects generate return waveforms that appear to be more

extended in time. This is consistent with previous observations of overlapping return echoes from multiple targets.

Upcoming Activities: An informal review of the CWD effort is scheduled for June 13 with Mr. David Ferris at Jaycor's facility in San Diego, CA. We are also planning on attending the NIJ TWS/CWD review to be held at the SPAWAR facility in San Diego sometime in August.

Progress Report #5 **3 September, 2001**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 June to 31 August, 2001

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 June, 2001 to 31 August, 2001. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Management/Schedule: As of 13 September, we are currently entering the fourteenth month of this 20-month effort with about 40% of the total program budget having been expended. We anticipate being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: An informal program review was held at Jaycor's San Diego, CA facility on 13 June. In attendance were Mr. David Ferris (Rome Lab/AFRL), Dr. Norbert Wild (Jaycor) and Mr. Steve Niederhaus (Jaycor). An electronic copy of the briefing was delivered to Mr. Ferris.

An additional briefing was prepared and given on Aug 9 at the SPAWAR facility in San Diego as part of the NIJ TWS/CWD program review. An electronic copy of the briefing was delivered to Ms. Tracy Coffman at RL/AFRL.

Laboratory Tests:

During the month of August, testing of the completed multiple transducer configuration was carried out and the results compared with the single transducer scheme. As a function of angular sensitivity, the addition of two or four separate transducer illuminators did not significantly enhance (< 10%) the observed return signal for a variety of target types. These included a 4-inch square flat plate (smooth surface and rough surface), a 6-inch spherical target, a ½-inch cylindrical target, and two different handguns (Beretta and Smith & Wesson). In light of these results, it appears that multiple source illuminators will not be beneficial in terms of being able to increase the sensitivity to off-angle reflections from hard objects.

In order to reduce battery requirements (and the overall weight of the detector unit) the incandescent bulb being used as an aiming light will be replaced with a small low-power (eye-safe) laser pointer. This will allow for a single voltage battery pack to be used and a design for incorporating the battery into the handle of the sensor is being drawn up.

Signal Processing: Changes to the existing electronics signal processing are being made that will allow for increased range (out to 25-30 feet). These included changes to the variable gain amplifier circuit, the receiver pre-amp stage, and the alarm display circuitry.

Fabrication of Prototype Deliverables: Fabrication of the 20 prototypes to be delivered to AFRL has begun with orders being placed for various required piece parts. A CAD drawing of the electronic circuit board is being generated and will be sent to local circuit board vendors for quotes on fabrication. A redesign of the housing has also been initiated. The new design will focus on making the unit lighter in total weight and be more ergonomically compatible with handheld use.

Upcoming Activities: No extra-curricular activities are planned for the upcoming reporting period.

Progress Report #6 **3 December, 2001**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 September to 30 November, 2001

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 September, 2001 to 30 November, 2001. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Management/Schedule: As of 1 December, we are currently entering the seventeenth month of this 20-month effort with about 60% of the total program budget having been expended. We remain on track with regards to being able to meet all program objectives with the remaining resources and within the planned schedule.

Meetings: No external meetings were held during the reporting period. Internal meetings were held regarding fabrication of the housing assembly for the handheld CWD sensor with various local manufacturers. Scicon was tentatively chosen as the most capable candidate for fabricating the initial molds and subsequent castings for the housing assembly. Two additional vendors, ForeCast and R&D Design Engineering, are also being considered. Scicon was the fabricator of the original parabolic dish reflectors used in the prototype design under the previous effort. Additional meetings were also scheduled to finalize the electronics circuit board design layout and fabrication. The circuit board will be manufactured by a local company, Proto Qwik.

Laboratory Tests:

Laboratory testing was concentrated on verifying the extended range operation of the detector in a laboratory setting. Representative targets, e.g., real Smith & Wesson revolver, cell phone, personnel pass card, and plastic knife, were examined at various distances under a variety of cloth types for several different view angles. Detectivity was verified for all targets out to 25 feet range under light clothing, e.g., T-shirt, flannel shirt, and wool sweater.

Additional testing was also conducted to verify that the addition of multiple off-axis transmitters did not result in any significant increase in the probability of detection. As proposed originally, it was felt that extra off-axis transmitters would allow for increased ease of use in detecting narrow angle return glints from hard objects. The latest results show that the sensitivity is relatively constant, even with additional illumination from off-axis angles out to 15 degrees. Thus, the final design will not incorporate these off-axis transmitters.

Signal Processing: No additional changes to the signal processing have been made during the reporting period with the exception of extending the blank off time from 40 msec out to 65 msec to accommodate the extended range (from 18 feet to 30 feet).

Fabrication of Prototype Deliverables: Fabrication of the 20 prototypes to be delivered to AFRL is continuing with most of the required piece parts having been delivered. The finalized schematic of the electronic circuit board will be delivered to a local vendor for Gerber layout and then fabrication by a separate vendor (Proto Qwik). An initial quote for fabrication of 35 boards was $2,400.

The plastic housing design is show in Figures 1 through 4. Fabrication quotes have been received from a local prototyping vendor (Scicon) and additional quotes are expected soon from ForeCast and R&D Design Engineering. Total mold and casting costs are estimated to run $9,700 for molds and $190 casting per sensor.

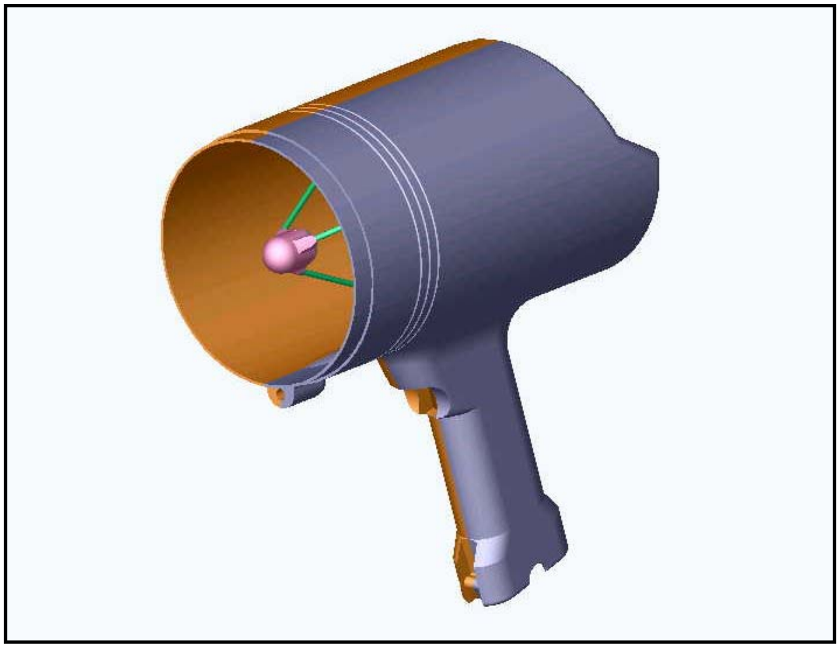


Fig. 1 – Engineering drawing of handheld CWD sensor prototype.

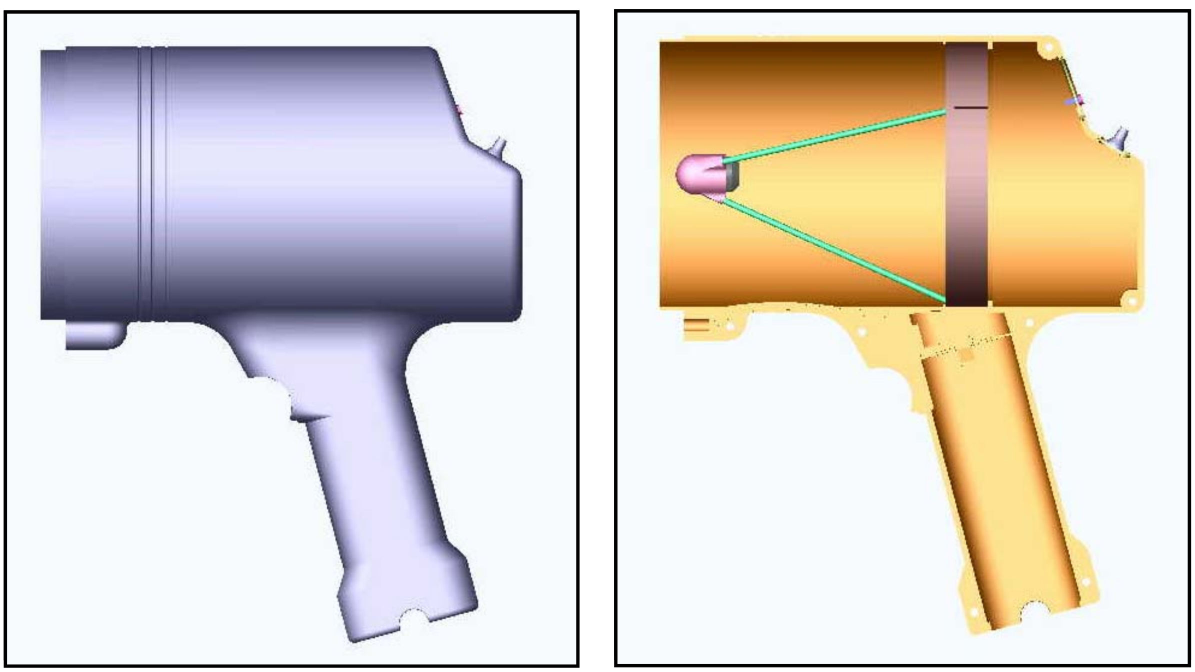


Fig. 2 – Side view of housing and interior transducer and parabolic dish components.

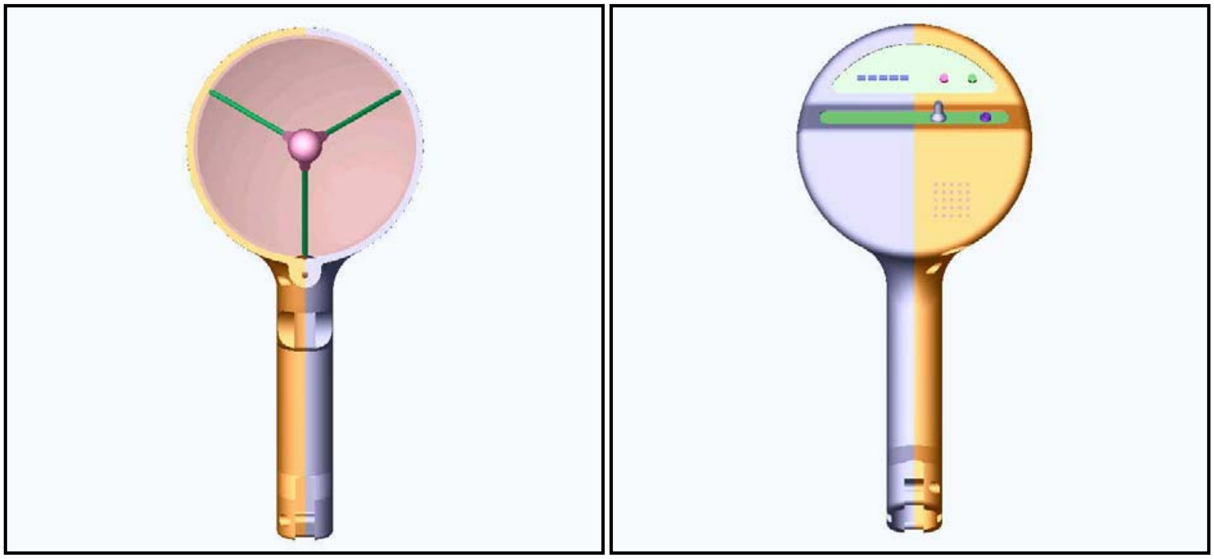


Fig. 3 – Front and rear views of prototype design showing tripod transducer mount (front view) and rear controls and display (rear view).

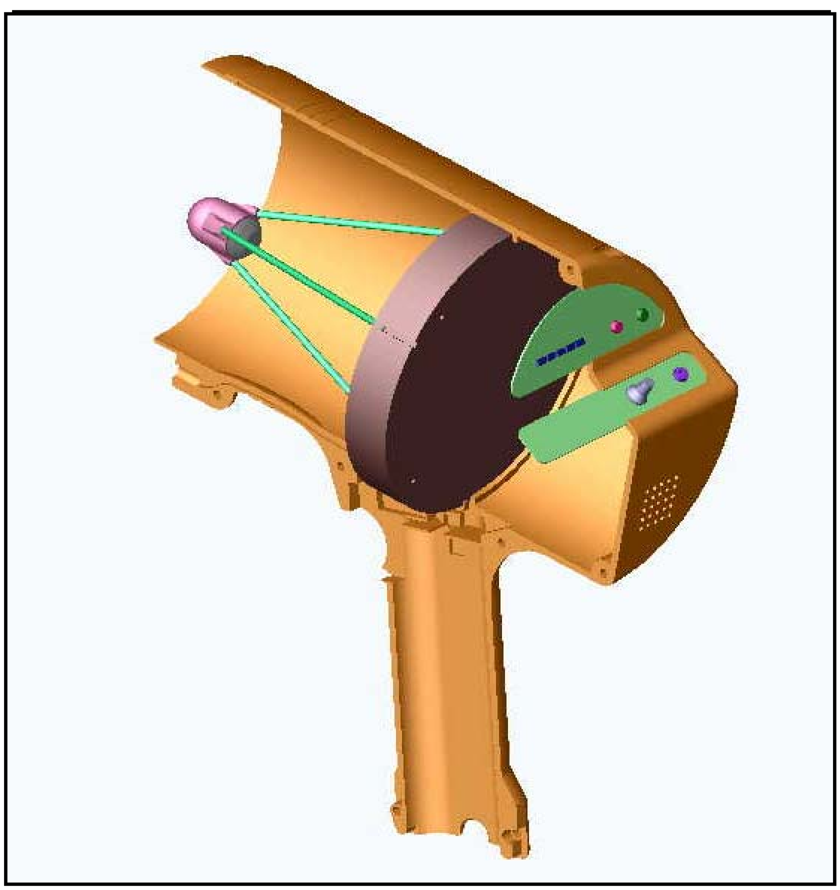


Fig. 4 – Cut-away view of the housing, transducer, parabolic dish and external display and controls. Battery will be located in the handle; electronics board behind the dish.

Upcoming Activities: No extra-curricular activities are planned for the upcoming reporting period.

JAYCOR

Progress Report #7 **28 August, 2002**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 December, 2001 to 28 February, 2002

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 December, 2001 to 28 February, 2002. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Meetings: Several internal meetings were held to finalize the electronics circuit board design layout and fabrication. The circuit board will be manufactured by a local company, Proto Qwik.

Prototype Fabrication Status

A decision was made to use a low power laser diode pointer assembly as an aiming light option. Of the 20 prototype units being fabricated, 16 will utilize this type of aiming light. The laser diode pointer was found to be more visible in daylight and also easier to align with the acoustic dish. The main advantage, however, is the much lower power consumption and subsequent weight savings in battery storage.

A breadboard of the entire electronic circuit was completed and debugged including a new pre-amp filter design with lower noise floor characteristics. A new power supply design was also implemented that will allow for a single battery supply to operate the entire assembly. The variable high-gain amplifier stage was also modified to allow for increased range (out to 30 feet).

Housings and parts were ordered for the aiming light/transducer assembly and parabolic dish and holder stage. Components and how they will be laid out on the back panel were also determined and ordered.

Upcoming Activities: Plans have been made to attend the SPIE Aerosense 2002 Conference to be held in Orlando, Florida in April.

Progress Report #8 **28 August, 2002**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 March to 31 May, 2002

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 March, 2002 to 31 May, 2002. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Meetings: Dr. Wild attended the SPIE Aerosense 2002 Conference held in Orlando, Florida during the first week in April. A presentation was made on the CWD effort.

Prototype Fabrication Status

After several series of laboratory tests, the maximum drive voltage for the 40 kHz transducers was optimized at 350 V peak-to-peak. Larger drive voltages give increased return signals at a given range but also result in premature failure of the transducer in some cases.

The electronics assembly continues to undergo fine tuning to optimize the range and detectability. A passive acoustic lens was also tested for dispersion and amplification properties but will not be used in the final design. The high gain variable amplifier stage was change from a single to a dual stage design to minimize noise levels and to allow for operation at increased ranges (out to 30 feet). All drawings were modified and updated to reflect these changes.

Display panel parts were ordered as well as the printing on the back display panel. A redesign of the aiming light/transducer housing parts was completed to accommodate the incandescent light bulb.

Upcoming Activities: Plans were made to attend the annual AFRL/NIJ program review to be held at Ft. Belvoir in August.

Progress Report #9 **28 August, 2002**

Handheld Concealed Weapons Detector Development

F30602-00-C-0204

Jaycor 3148

Reporting Period: 1 June to 31 August, 2002

Submitted to:

Mr. David Ferris
AFRL/IFEA
32 Brooks Rd.
Rome, NY 13441-4114

Submitted by:

Jaycor
P.O. Box 85154
San Diego, CA 92186-5154

This report describes all work performed under the referenced contract during the period from 1 June, 2002 to 31 August, 2002. A brief summary of tasks accomplished and progress made during the period is presented, followed by a synopsis of future plans and activities.

Meetings: Dr. Wild and Dr. Coakley, both from Jaycor – Titan Systems, attended the AFRL/NIJ Program Review held at Ft. Belvoir on 6-7 August. Dr. Wild made a presentation on the status of the CWD effort and showed an example of the second generation prototype device.

Prototype Fabrication Status

Final changes were made to electronics circuit and then the design was sent out for layout and fabrication. Fabricated boards were received during mid-July. First populated board was tested and found to be OK. Subsequent boards were then populated and tested as they became available.

All molded parts were received and tested for form and fit and found to be acceptable. O-rings were ordered to hold the two halves together (in addition to screws) and also for aesthetic appeal. Display panel components were received and then the display panels were assembled and tested.

Final assembly of all components took place during August. Final calibration and tests were completed and 16 units with laser diode aiming lights were ready for shipment to AFRL. Four units with the incandescent bulb aiming lights are on hold pending a rework of the bulb assembly. These units should be available by mid-September.

Upcoming Activities: Plans were made to ship 20 second-generation prototype CWD units to AFRL for evaluation. A Final Report was assembled and will be submitted in September.

APPENDIX E

Concealed Weapons Detection Unit

CWD-2002

Operation and Instruction Manual

Introduction

This manual is designed to acquaint the user with the various features and operating characteristics of the CWD-2002 handheld concealed weapons detection unit. The CWD-2002 unit is a second generation prototype sensor designed to detect and locate acoustically reflective objects (metallic or non-metallic) that may be hidden or concealed beneath articles of clothing. The effective range of the device is from 5 feet out to 25 feet.

It is important for the user to realize that the sensor does not discriminate between a potentially dangerous object such as a handgun or knife and other objects that someone may normally carry on their person, e.g., cell phone, wallet, etc. The main purpose of the sensor is to give the user an additional tool to either pre-screen individuals or give law enforcement users probable cause to perform more thorough pat-down searches.

It is also imperative to understand that the sensor is not fool-proof. That is, a concealed weapon can go undetected by the CWD-2002 unit if the person is wearing sufficiently thick clothing, the weapon does not reflect enough acoustic energy back into the sensor, or if the operator is not proficient in the use of the device. The CWD-2002 unit can not see through an individual; the person being scanned must be directed to turn 360 degrees so that all sides are available for viewing by the sensor.

With these two main caveats in mind, the CWD-2002 should provide law enforcement personnel a valuable tool for screening individuals for concealed weapons in a variety of settings, e.g., prisons, points of entry, etc.

Operation

When installing the rechargeable battery into the battery compartment in the hand grip, it is important to make sure that the battery is oriented properly. A raised area on one side of the battery should match up with the keyed depressed area in the hand grip compartment to ensure proper operation. Failure to install the battery in its proper orientation will result in an inoperable unit and can potentially damage some of the voltage regulation electronics.

The CWD-2002 utilizes short bursts of high frequency (40 kHz) acoustic energy to penetrate clothing and detect objects with reflection coefficients greater than human tissue. The unit is equipped with an aiming light (either incandescent or low energy laser diode) to allow the user to determine the area being scanned. A separate on/off switch controls power to the aiming light which is then activated via the pull trigger. The pull trigger also initiates the acoustic transmitter and receiver electronics.

Figure 1 shows the backpanel display. There are five colored LEDs located in an arc on the left, a volume control knob and headphone jack in the middle, and “LOW BATT.” and “AIMING LIGHT” indicators on the right. When the trigger is pulled, the green “ON” LED should light. The strength of the return signal is indicated by the number and color of the LEDs that are lit above the ON indicator. For low level return signals, one or two of the yellow LEDs may light. Depending on the type of clothing that an individual is wearing, these can light up in many instances where no concealed items are present. For strong return signals, the top one or two red LEDs will also turn on. If these are lit while scanning a specific site on the individual, there is a high probability that a concealed object is present there. With experience in using the device, the user can complete a full scan (360 degree rotation) of an individual in less than 1 minute.

Fig. 1 – Photograph of the rear panel display on the CWD-2002.

The audible detection indicator is designed to chirp at a fixed frequency. As the return signal increases, the rate of chirping becomes faster. The audible indicator can be turned off using the volume control knob (in which case the user

must rely solely on the visible LED indicators) or the user can choose to use the supplied headphones for more covert operation.

The size of the area being scanned depends to some extent on the range to the individual. That is, at distances from the minimum operating range of 5 feet out to a range of about 12 feet, the spot size is less than 1 foot in diameter. At the maximum range of 25 feet, the spot size is about 2 feet in diameter. Thus, any reflective object in this area can potentially return a signal large enough to activate the receive LED indicators on the back panel display. Figure 2 illustrates the two kinds of aiming lights available for the CWD-2002.

COLLIMATED QUARTZ HALOGEN

RED LASER DIODE

Fig. 2 – Two different types of aiming lights are available for the CWD-2002.

Due to the high degree of collimation of the transmitted acoustic pulse, the field of view of the sensor is also limited. That is, one can be scanning an area with a concealed object and not "see" the object because the reflected signal does not lie within the field of view of the sensor. With practice, by moving the device through a number of different angles while scanning the same spot, the number of false negatives (no indication of a concealed object) will decrease.

The sensor works best when operated indoors or in sheltered areas. That is, air motion at the extended ranges (18-25 feet) can impair the ability of the sensor to distinguish between real concealed objects and a clothing's normal reflectance. Also, the sensor will not function during rain and should not be immersed in water. While reasonably rugged, sudden impacts can potentially misalign the aiming light and also damage the acoustic transducer.

Scanning Techniques

The scanning of an individual for concealed weapons should be performed with the target individual standing in one spot. A complete scan of the individual is

then accomplished while having the person turn 360 degrees around to provide for full body coverage. The detector can be held with the handle oriented either vertically or horizontally, depending upon the operator's preference. While examining a specific area on the target individual, the detector should be moved side to side and up and down to insure that the viewing angle is as wide as possible. If a concealed object is indicated, scan a different part of the body and then return to the suspect area to confirm the reading.

While the detector is designed to ignore reflections from objects such as walls and furniture located behind a target individual, it helps to have the target individual stand in an area with a minimum of 2 feet of space on either side and behind the individual.

We have found that the probability of detection increases as the operator becomes more familiar with using the device. Practicing on a cooperative individual with a known object (cell phone, block of wood, etc.) concealed under light clothing helps to train potential operators to use the detector more efficiently.

Battery Replacement

Please note that the rechargeable batteries MUST be inserted in the proper orientation in the handgrip battery compartment. A raised area on one side of the battery should match up with the keyed area in the battery compartment for proper operation. It is possible to forcibly install the battery backwards but this will result in an inoperable unit and may potentially damage some of the voltage regulator electronics.

There is no quiescent power draw from the rechargeable battery in the handgrip when the trigger is not pulled. In normal use, battery life is on the order of 2-3 weeks. A battery recharging station is supplied to allow for minimal down time as a result of normal battery discharge. When battery recharging is needed, the red "Low Batt." LED will come on. Battery removal is accomplished by simply opening the black snap-clip at the bottom of the handgrip. The discharged battery should be placed in the charging station and will normally fully recharge in a period of 3-4 hours. Additional batteries are available from Jaycor's San Diego facility.

Technical Support

Please contact Mr. Steve Niederhaus (858-720-4078) at Jaycor - Titan Systems for any questions regarding maintenance, repair or battery issues.

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National Institute of Justice. Programmatic questions can be addressed to the Air Force Technical Monitor, Mr. David Ferris (315-330-4408) or to the Jaycor Principal Investigator, Dr. Norbert Wild (858-720-4085).